Chapter 3
Risk Screening and Comparison

This chapter of the Cleaner Technologies Substitutes Assessment (CTSA) addresses the health and environmental hazards, exposures, and risks that may result from using a surface finishing technology. The information presented here focuses entirely on the surface finishing technologies. It does not, nor is it intended to, represent the full range of hazards or risks that could be associated with printed wiring board (PWB) manufacturing. This risk evaluation is a screening-level assessment of multiple chemicals belonging to the surface finishing use cluster, and is presented as a screening level rather than a comprehensive risk characterization, both because of the predefined scope of the assessment and because of exposure and hazard data limitations. The intended audience of this risk screening and comparison is the PWB industry and others with a stake in the practices of this industry.

Section 3.1 identifies possible sources of environmental releases from surface finishing and, in some cases, discusses the nature and quantity of those releases. Section 3.2 assesses occupational and general population (i.e., the public living near a PWB facility; fishing streams that receive wastewater from PWB facilities) exposures to surface finishing chemicals. This section quantitatively estimates inhalation and dermal exposure to workers and inhalation exposure to the public living near a PWB facility. Section 3.3 presents human health hazard and aquatic toxicity data for surface finishing chemicals. Section 3.4 characterizes the risks and concerns associated with the exposures estimated in Section 3.2. In all of these sections, the methodologies or models used to estimate releases, exposures, or risks are described along with the associated assumptions and uncertainties. Finally, Section 3.5 summarizes chemical safety hazards from material safety data sheets (MSDSs) for surface finishing chemical products and discusses process safety issues.

3.1   SOURCE RELEASE ASSESSMENT

The Source Release Assessment uses data from the PWB Workplace Practices Questionnaire, together with other data sources, to identify sources and amounts of environmental releases. Both on-site releases (e.g., evaporative or fugitive emissions from the process) and off-site transfers (e.g., off-site recycling) are identified and, for those where sufficient data exist from the questionnaire, numerical results are presented. The objectives of the Source Release Assessment are to:

C   identify potential sources of releases;
C   characterize the source conditions surrounding the releases, such as a heated bath or the presence of local ventilation; and
C   characterize, where possible, the nature and quantity of releases under the source conditions.

Many of the releases may be mitigated and even be prevented through pollution prevention techniques and good operating procedures such at those described in Chapter 6, Additional Environmental Improvement Opportunities. However, they are included in this assessment to illustrate the range of releases that may occur from surface finishing processes.

A material balance approach was used to identify and characterize environmental releases associated with day-to-day operation of surface finishing processes. Air releases and releases of organics to surface waters, which could not be quantified from the questionnaire data, are modeled in Section 3.2, Exposure Assessment.

Section 3.1.1 describes the data sources and assumptions used in the Source Release Assessment. Section 3.1.2 discusses the material balance approach used, release information, and data pertaining to all surface finishing process alternatives. Section 3.1.3 presents source and release information and data for specific surface finishing process alternatives. Section 3.1.4 discusses uncertainties in the Source Release Assessment.

3.1.1   Data Sources and Assumptions

This section presents a general discussion of data sources and assumptions for the Source Release Assessment. Sections 3.1.2 and 3.1.3 present more detailed information about specific inputs and releases for individual surface finishing alternatives.

Sources of data used in the Source Release Assessment include:

- industry data collection forms, such as the PWB Workplace Practices Questionnaire and Performance Demonstration Observer Data Sheets (Appendix A, Data Collection Sheets);
- supplier-provided data, including bath chemistry data and supplier Product Data Sheets describing how to mix and maintain baths (Appendix B, Publicly-Available Bath Chemistry Data);
- engineering estimates; and
- DfE PWB Project publication, *Printed Wiring Board Pollution Prevention and Control Technologies: Analysis of Updated Survey Results* (U.S. EPA, 1998a).

Bath chemistry data were collected in the PWB Workplace Practices Questionnaire, but these data were not used due to inconsistencies in the responses to questions pertaining to bath chemistry. Instead, surface finishing chemical suppliers participating in the Performance Demonstration submitted confidential chemical formulation data along with publicly-available Product Data Sheets on their respective product lines. Bath concentration ranges were determined based on this information using the method discussed in Section 2.1.4, Chemical Characterization of Surface Finishing Technologies. A general description of the PWB Workplace Practices Questionnaire, including its distribution and overall general results, is presented in Section 1.3.4, Primary Data Sources.

Several assumptions or adjustments were made to put the PWB Workplace Practices Questionnaire data into a consistent form for all surface finishing technologies. These include the following:

- Data reported on a daily basis were converted to an annual basis using the number of days per year of process operation (Appendix A, questions 2.2 and 3.2). For data on a weekly or monthly basis, 12 months per year and 52 weeks per year were assumed.
- Data reported on a per shift basis was converted to a per day basis using the number of hours per day the process was in operation, when available. Eight hours of operation was assumed to be equivalent to one shift.
- Bath names provided by questionnaire respondents were revised to be consistent with the generic surface finishing process descriptions provided in Section 2.1.3, Chemistry and Process Descriptions of Surface Finishing Technologies.

There were wide variations in submitted data due to the differences in size of PWB facilities. To adjust for this, data are presented here both as reported in the questionnaire (usually as an annual quantity consumed or produced), as well as normalized by annual surface square feet (ssf) of PWB produced by the individual surface finishing technology. Normalizing the data, however, may not fully account for possible differences in processing methods that could result from different production levels.

3.1.2   Overall Material Balance for Surface Finishing Technologies

A general material balance is presented here to identify and characterize inputs and potential releases from the surface finishing process alternatives. Due to limitations and gaps in the available data, no attempt was made to perform a quantitative mass balance of inputs and outputs. This approach is still useful, however, as an organizing tool for discussing the various inputs to, and outputs from, surface finishing processes, and presenting the available data. Figure 3-1 depicts inputs to a generalized surface finishing process line, along with possible outputs, including PWB product, solid waste, air emissions, and wastewater discharges.

Many PWB manufacturers have an on-site wastewater treatment system for pretreating wastewater prior to direct discharge to a stream or lake, or indirect discharge to a publicly owned treatment works (POTW). Figure 3-2 describes a simplified PWB wastewater treatment system, including the inputs and outputs of interest in the Source Release Assessment.
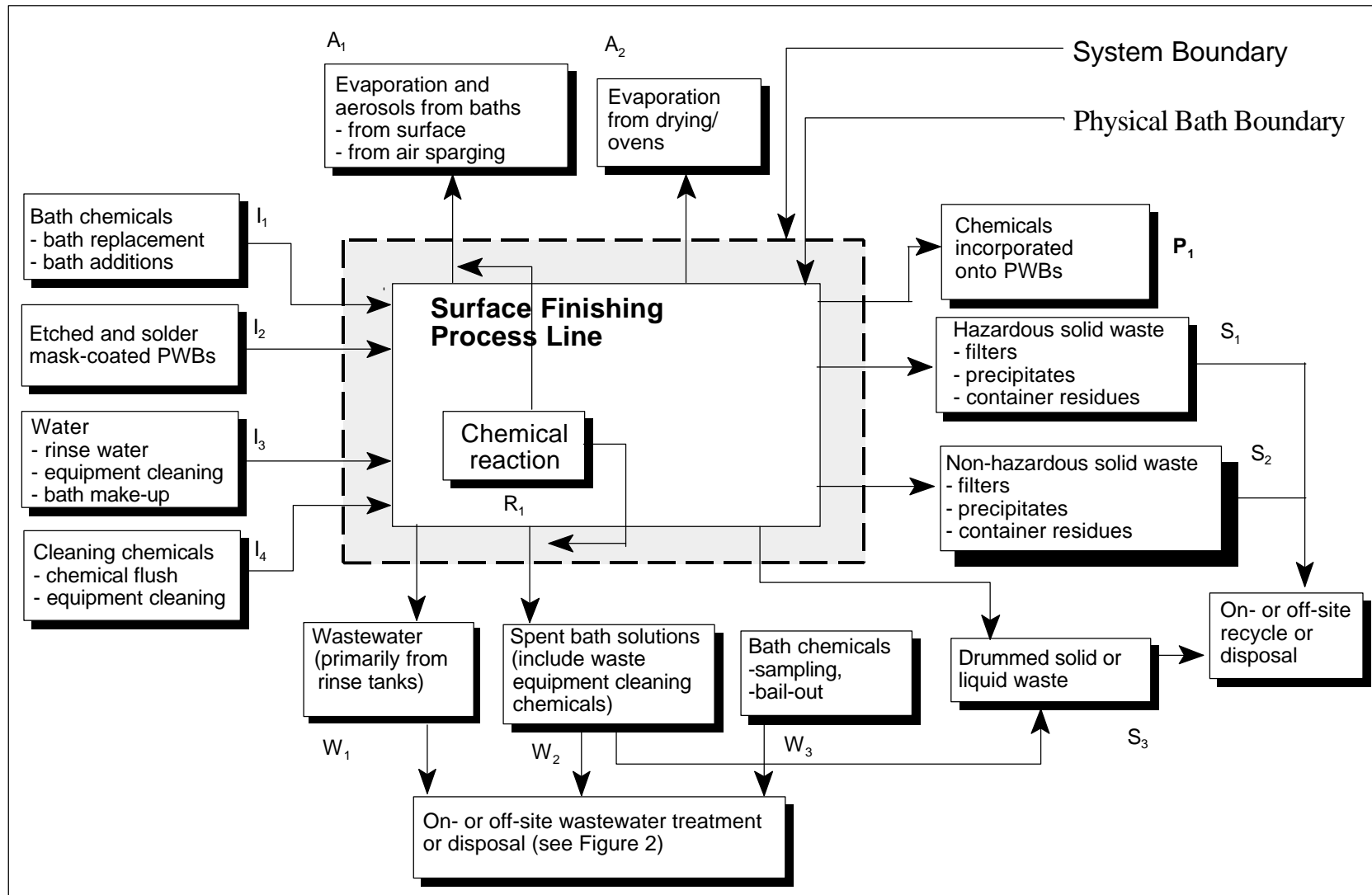
Figure 3-1. Schematic of Overall Material Balance for Surface Finishing Technologies
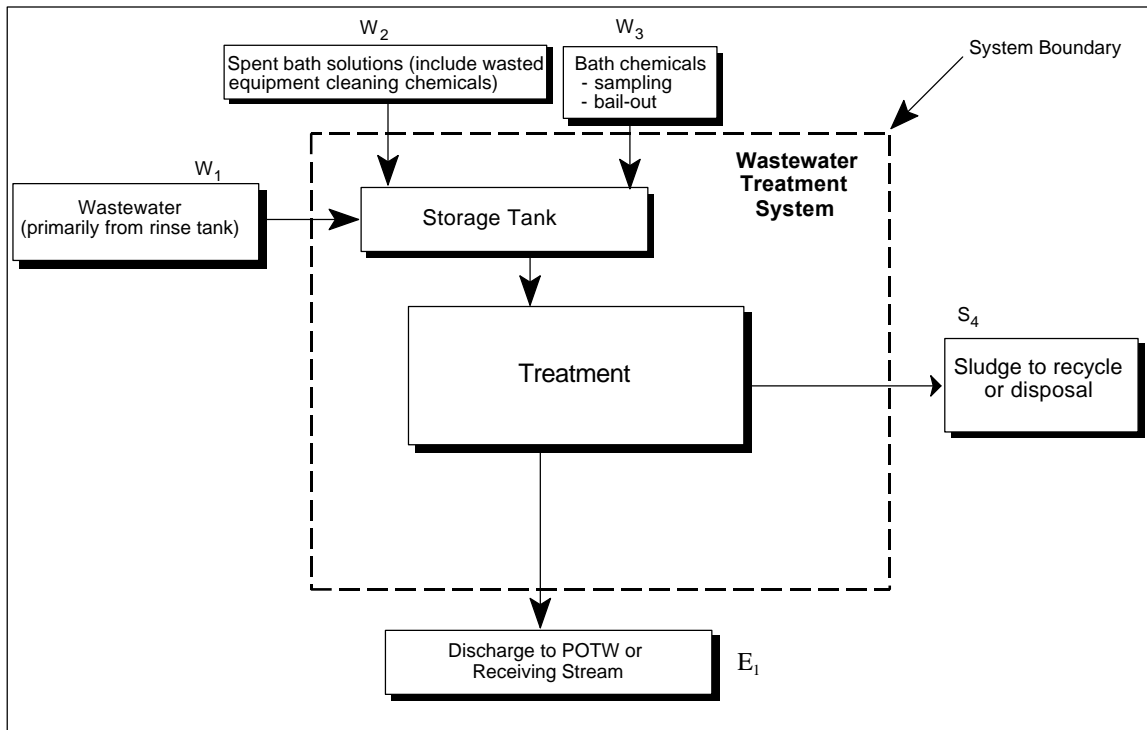
Figure 3-2. Wastewater Treatment Process Flow Diagram

Inputs

Possible inputs to a surface finishing process line include process chemicals and materials, etched and solder mask-coated PWBs that have been processed through previous PWB manufacturing process steps, water, and cleaning chemicals.

The total inputs for the process are described by the equation:

$$I_{total} = I_1 + I_2 + I_3 + I_4$$

where,

I_1	=	bath chemicals
I_2	=	etched and solder mask-coated PWBs
I_3	=	water
I_4	=	cleaning chemicals

These terms are discussed below.

I_1 *Bath chemicals.* This includes chemical formulations used for initial bath make-up, bath bailout and additions, and bath replacement. Bath formulations and the chemical constituents of those formulations were characterized based on Product Data Sheets and bath formulation data provided by the chemical suppliers. A detailed description of the

calculation of bath chemical concentrations is presented in Section 2.1.4, Chemical Characterization of Surface Finishing Technologies. Calculated chemical bath concentrations are reported in Appendix B. PWB manufacturers were asked to report the quantity of surface finishing chemicals they use annually in the PWB Workplace Practices Questionnaire. However, the resulting data were variable and poor in quality, preventing the quantification of total chemical usage for process chemicals.

I_2 *Etched and solder mask-coated PWBs.* PWBs with solder mask-coated copper circuitry that enter the surface finishing line could lose a small amount of copper to the process line due to etching and dissolution. Trace amounts of other additives such as arsenic, chromium, and phosphate may also be lost to the process. This applies to all surface finishing alternatives where copper is etched off the boards in the microetch bath at the beginning of the process.

PWB panels are the only source of copper for the surface finishing process. The rate at which the copper is lost can vary depending on process conditions (e.g., bath temperature, chemical concentration of bath, etc.) and the type of bath (whether a microetch bath or a plating bath). The amount of copper lost through etching and through displacement plating mechanisms is expected to be small, relative to other chemical additions. This input is not quantified.

I_3 *Water.* Water, usually deionized, is used in the surface finishing process for rinse water, bath make-up, and equipment cleaning. The water consumption of surface finishing technologies varies according to the number and size of rinse tanks used by the process. However, the number of rinse tanks can also vary from facility to facility within a technology category due to differences in facility operating procedures, rinse configuration, and water conservation measures.

Water usage data collected by the PWB Workplace Practices Questionnaire include the daily volume of water used for rinse water and bath make-up. Daily water usage in gallons was converted to annual water usage by multiplying by the number of days per year the process was in operation. The value was then normalized by dividing the annual water usage in gallons by the annual production in ssf of PWB produced for the same line. Both annual and normalized water consumption data from the questionnaire for each surface finishing technology are summarized in Table 3-1.

From the normalized data it can be seen that the nickel/gold and nickel/palladium/gold processes consume more water per ssf than the other technologies. The increased water consumption is due to the bath sequences of these technologies which are typically longer and thus use more rinse tanks. Drawing other conclusions from this data is difficult, given the variation in PWB throughput between reporting facilities and the relatively few number of responses within some technology categories.

Table 3-1. Water Usage of Surface Finishing Technologies From Questionnaire

Process Type	No. of Responses	Water Usage (I_3) (thousand gal/year)[a]	Water Usage (I_3) (gal/ssf)
HASL			
Non-conveyorized	6	0.3 - 750 (254)	0.970
Conveyorized	17	910 - 3,740 (1,250)	4.89
Nickel/Gold			
Non-conveyorized	8	17 - 1,620 (538)	101
Nickel/Palladium/Gold			
Non-conveyorized	2	216 - 1,710 (961)	164
OSP			
Non-conveyorized	5	42 - 150 (89.1)	1.93
Conveyorized	5	8 - 1,580 (440)	14.3
Immersion Silver			
Conveyorized	2	698 - 1,120 (907)	36.8
Immersion Tin			
Non-conveyorized	4	3.3 - 385 (209)	11.0
Conveyorized	2	11.5 - 199 (105)	0.333

[a] Average values from the PWB Workplace Practices Questionnaire data are shown in parentheses. Refer to Section 1.3.4 for a detailed discussion of questionnaire responses.

I_4 *Cleaning chemicals.* This includes chemicals used for conveyor equipment cleaning, tank cleaning, chemical flushing, rack cleaning, and other cleaning pertaining to the surface finishing process line. Data were collected by the PWB Workplace Practices Questionnaire regarding the use of chemicals to clean conveyors and tanks (questions 2.8, 3.8, 2.13, and 3.13). Three respondents with OSP, one with immersion tin, and one with the hot air solder leveling (HASL) technology use chemicals to clean their conveyor systems.

Table 3-2 shows the number of times that chemical flushing was reported by respondents as the method for tank cleaning for each process bath. The electroless nickel bath in the nickel/gold process, and both the activator and electroless nickel baths in the nickel/palladium/gold process are the only process baths that were consistently reported to require chemical cleaning. The use of chemicals to clean other process baths was reported infrequently and appeared to be based upon the operating practices of the particular facility, rather than on any cleaning requirement specific to the technology.

Table 3-2. Reported Use of Chemical Flushing as a Tank Cleaning Method

Process Type	Bath Type	Number of Respondents Using Chemical Flushing[a]
HASL	Microetch	1 (27)
	Flux	2 (27)
	Solder	5 (28)
	Pressure Rinse	1 (22)
Nickel/Gold	Acid Dip	1 (8)
	Electroless Nickel	8 (8)
	Immersion Gold	1 (8)
	Microetch	1 (8)
	Other Bath	5 (9)
Nickel/Palladium/Gold	Microetch	1 (1)
	Acid Dip	1 (1)
	Activator	2 (2)
	Electroless Nickel	2 (2)
	Electroless Palladium	1 (2)
	Immersion Gold	1 (1)
OSP	OSP	4 (9)
Immersion Silver	Predip	1 (2)
	Immersion Silver	2 (2)
Immersion Tin	Immersion Tin	1 (4)

[a] Total number of questionnaire responses for process bath are shown in parentheses.

Outputs

Possible outputs from a surface finishing process line include finished PWBs, air emissions, wastewater discharges, and solid wastes.

Product Outputs. Product outputs include the following:

P_1 *Chemicals incorporated onto PWBs during the surface finishing process*. This includes the PWBs along with lead, tin, silver, palladium, nickel, gold, and/or organic compounds that are coated onto the PWB surface. This output is not quantified.

Air Releases. Chemical emission rates and air concentrations are estimated by air modeling performed in Section 3.2, Exposure Assessment. The sources of air releases and factors affecting emission rates are summarized below.

The total outputs to air are given by the equation:

$$A_{total} = A_1 + A_2$$

where,

A_1 = evaporation and aerosol generation from baths
A_2 = evaporation from drying/ovens

These terms are discussed below.

A_1 *Evaporation and aerosol generation from baths.* Potential air releases from the process include volatilization from open surfaces of the baths as well as volatilization and aerosols generated from air sparging, which is used in some baths for mixing. These releases to both the occupational and outside environments are quantified in Section 3.2, Exposure Assessment. Gases formed by chemical reactions, side reactions, and by chemical plating in baths also contribute to air releases. However, they are expected to be small compared to volatilization and aerosol losses, and are not quantified.

Air releases may be affected by open bath surface area, bath temperature, bath mixing methods, and vapor control methods employed. Questionnaire data for bath agitation and vapor control methods are summarized below:[1]

C Most facilities using conveyorized processes use fluid circulation pumps to mix the baths. Panel agitation is also used as a mixing method by several facilities, while air sparging was seldom reported (more than one method can be used simultaneously).

C The majority of vapor control methods reported are fully-enclosed and vented to the outside. Only a few of the conveyorized processes use a push-pull[2] system for vapor control.

C For facilities using non-conveyorized processes, most use either panel agitation or circulation pumps to mix the tanks. Only about ten percent of the facilities use air sparging as a tank mixing method, which could generate aerosols and enhance volatilization from the baths.

C Frequently-used vapor control methods for non-conveyorized process baths include vent-to-outside (approximately 60 percent) and bath covers (20 percent), while seldom-reported methods include push-pull systems or fully enclosed baths.

Table 3-3 lists average bath surface area, volume, and bath temperature data from the PWB Workplace Practices Questionnaire. Some of this information (both surface area and temperature) is used to model air releases in the Exposure Assessment. Surface areas are calculated from reported bath length and width data. Larger bath surface areas enhance evaporation. Most of the baths are maintained at elevated temperatures, which also enhance evaporation.

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[1] From Questionnaire, questions 2.10 and 3.10.

[2] Push-pull ventilation combines a lateral slot hood at one end of the tank with a jet of push air from the opposite end. It is used primarily for large surface area tanks where capture velocities are insufficient to properly exhaust fumes from the tank.

Table 3-3. Average Bath Dimensions and Temperatures for All Processes [a]

Bath	No. of Responses	Length (in.)	Width (in.)	Surface Area [b] (sq. in.)	Volume (gal.)	Temp. (ºF)
HASL, Non-conveyorized						
Cleaner	3	28	20	540	33	74
Microetch	5	28	27	720	57	105
Dry	1	!	!	!	!	135
Flux	7	33	22	760	5	76
Preheat	1	!	!	!	!	244
Solder	6	34	23	870	10	515
Air Knife	1	!	!	!	!	123
Pressure Rinse	6	63	32	1900	41	91
HASL, Conveyorized						
Cleaner	6	24	24	580	40	70
Microetch	16	50	32	1700	92	90
Dry	1	37	9	330	!	140
Flux	15	29	25	810	15	80
Preheat	1	38	37	1400	!	180
HASL	15	35	25	990	18	523
Air Knife	2	38	37	1400	!	231
Pressure Rinse	15	67	34	2255	104	97
Nickel/Gold, Non-conveyorized						
Cleaner	6	25	17	310	44	118
Microetch	7	26	17	370	43	93
Catalyst	6	23	17	300	33	165
Acid Dip	7	26	17	360	42	75
Electroless Nickel	7	27	19	430	52	185
Immersion Gold	7	26	17	370	43	181
Nickel/Palladium/Gold, Non-conveyorized						
Cleaner	2	29	20	540	26	119
Microetch	2	25	21	440	55	97
Catalyst	2	33	10	330	50	134
Acid Dip	2	21	14	250	34	!
Electroless Nickel	2	24	14	270	36	181
Electroless Palladium	1	35	10	350	43	125
Immersion Gold	2	21	14	250	32	183
OSP, Non-conveyorized						
Cleaner	4	27	24	580	83	121
Microetch	5	25	25	570	82	83

Bath	No. of Responses	Length (in.)	Width (in.)	Surface Area [b] (sq. in.)	Volume (gal.)	Temp. (ºF)
OSP	4	27	24	580	86	124
OSP, Conveyorized						
Cleaner	3	36	30	1100	56	113
Microetch	5	35	34	1300	63	99
OSP	5	72	34	2600	125	108
Immersion Silver, Conveyorized						
Cleaner	2	34	31	1000	65	81
Microetch	2	42	31	1300	80	73
Predip	2	47	31	1600	60	86
Immersion Silver	2	143	31	4400	142	113
Dry	1	!	!	!	!	149
Immersion Tin, Non-conveyorized						
Cleaner	2	27	18	500	49	104
Microetch	2	27	18	500	49	103
Predip	1	30	24	720	60	!
Immersion Tin	2	27	18	500	47	150
Immersion Tin, Conveyorized						
Cleaner	2	39	31	1500	100	105
Microetch	2	39	31	1500	100	95
Predip	2	31	14	450	33	101
Immersion Tin	3	47	31	1400	140	133
Dry	2	!	!	!	!	165

[a] Based on PWB Workplace Practices Questionnaire data.
[b] All of the surface areas present in the table are average values of individual bath areas; they are not obtained by multiplying the average length by the average width.
! No responses were given to this question in the questionnaire.

A$_2$ *Evaporation from drying/ovens.* Air losses due to evaporation from drying steps apply to HASL, OSP, immersion tin, and immersion silver processes with air knife, oven, or air cool steps. Releases for each process type are discussed qualitatively in Section 3.1.3.

Water Releases. Potential outputs to water include chemical-contaminated wastewater from rinse tanks, equipment cleaning, spent bath solutions, and liquid discharges from bath sampling and bail-out. Wastewater streams from the surface finishing process line are typically pre-treated by an on-site treatment system prior to being discharged from the facility. Spent bath chemicals that are considered hazardous, or are too difficult to treat on-site, are drummed and sent off-site for treatment. Waste streams with similar treatment requirements (e.g., chelated waste streams) may be segregated from the other wastes and batch treated together. All remaining liquid wastes are combined with similar wastes from other PWB manufacturing

processes prior to treatment. The co-mingled wastewater streams are then treated to meet the discharge limits for the facility. Once treated, the wastewater is discharged to a POTW or directly to a receiving stream. Facilities that directly discharge to a stream require a National Pollution Discharge Elimination System (NPDES) permit. Out of the 47 total survey respondents, 36 facilities indirectly discharge to POTWs while 10 facilities directly discharge to receiving streams. A detailed description of on-site treatment systems is presented in Section 6.2, Recycle, Recovery, and Control Technologies Assessment.

The total outputs to water are given by the equation:

$$W_{total} = W_1 + W_2 + W_3$$

where,
W_1 =   wastewater
W_2 =   spent bath solution
W_3 =   bath sampling and bail-out

These terms are discussed below.

W_1 *Wastewater.* Chemical-contaminated rinse water is the largest source of wastewater from the surface finishing process line, resulting primarily from drag-out. The term drag-out refers to the process chemicals that are 'dragged' from chemical baths into the following water rinse stages, where they are washed from the board, resulting in contamination of the rinse water. Drag-out losses account for approximately 95 percent of uncontrolled bath losses [i.e., losses other than from bath replacement, bail-out, and sampling (Bayes, 1996)]. Because the volume of water consumed by the rinse steps greatly exceeds the water consumed by all other water uses, the quantity of wastewater generated by the process is assumed to be equal to the overall water usage (I_3). Daily water usage data were collected in the PWB Workplace Practices Questionnaire (questions 2.6 and 3.6), with the resulting data of variable to poor quality. The previous discussion of water usage data also applies to wastewater amounts.

In the absence of quality data from industry, a model was developed to estimate the mass loading of constituents within the wastewater, resulting from drag-out, during the production of 260,000 ssf of PWB by the surface finishing process. The mass of chemical transferred per day to the wastewater, as well as other model results, are presented in Appendix E. A detailed description of the model along with the methods of model development, validation and testing, and model limitations are presented in *Prediction of Water Quality from Printed Wiring Board Processes* (Robinson et al., 1999), part of which has been included in Appendix E. Operational practices, such as increased drainage time, that can be used to reduce chemical losses, are described in Section 6.1, Pollution Prevention.

W_2 *Spent bath solution.* The concentration of chemicals within the process baths will vary, both as PWBs are processed through them, and as the baths age (e.g., volatilization,

evaporation, side reactions, etc.). These chemical baths are considered 'spent' once they have become too contaminated or depleted to properly perform, and are replaced with a new bath. During replacement, the spent bath chemistry is removed and the tank is cleaned, sometimes with cleaning chemicals, before a new bath is created. Depending on the chemicals involved, the spent bath chemistry will either undergo treatment on-site, or may be drummed and shipped off-site for treatment when hazardous. Waste equipment cleaning chemicals are also included in this waste stream.

Though requested, the data provided by industry respondents to the survey regarding the annual volume of bath chemistry disposed for each bath type (questions 2.13, 2.15, 3.13, and 3.15) was found to be of variable to poor quality. Instead, the annual volume of chemical solution disposed per bath type was calculated by determining the number of times a bath would require changing to produce a specific surface area of PWB, as described in Section 4.2, Cost Analysis. For the purposes of this assessment, chemical concentrations within the spent baths were assumed to be the same as concentrations at the time of bath make-up.

The methods of on-site treatment or disposal for individual spent baths were identified by questionnaire respondents. A summary of the spent bath treatment and disposal responses by technology type is presented in Table 3-4.

W$_3$ *Bath sampling and bail-out.* This includes bath samples disposed of after analysis and bath solution discarded through bail-out (sometimes done prior to bath additions). In some cases sampling may be performed at the same time as bail-out if the process bath is controlled by an automated monitoring system.

Routine bail-out activities, the practice of removing bath solution to make room for more concentrated chemical additions, could result in large volumes of bath disposal. Bail-out and bath addition data (e.g., frequency, duration and quantity) were collected in the PWB Workplace Practices Questionnaire, with the resulting data being of poor quality. Chemical loss due to bath sampling was assumed to be negligible.

Table 3-4. Spent Bath Treatment and Disposal Methods

Process Alternative	Total No. of Baths	Precipitation Pretreatment [a]	pH Neutralization [a]	Disposed to Sewer [a]	Drummed [a]	Recycled On-Site [a]	Recycle Off-Site [a]	Others
HASL	113	29	24	1	11	6	29	8
Nickel/Gold	55	35	25	0	2	2	4	5
Nickel/Palladium/Gold	14	8	3	0	7	1	1	0
OSP	28	14	15	0	4	1	0	0
Immersion Silver	8	3	3	1	2	0	0	0
Immersion Tin	17	3	6	0	5	3	0	0

[a] Number of affirmative responses for any bath from the PWB Workplace Practices Questionnaire, for all facilities using a technology category.

Wastewater Treatment. Figure 3-2 depicts the overall water and wastewater treatment flows, including wastewater, bath chemicals, and spent bath solution inputs to treatment, treatment performed on-site or off-site, sludge generated from either on-site or off-site treatment, and final effluent discharge to a POTW or receiving streams. PWB manufacturers typically combine wastewater effluent from other PWB manufacturing processes prior to on-site wastewater treatment. Sludge from on-site wastewater treatment is typically sent off-site for recycling or disposal. Detailed treatment system diagrams for each surface finishing technology are presented and discussed in Section 6.2, Recycle, Recovery, and Control Technologies Assessment.

E_1 *Wastewater effluent from treatment.* The mass-loading of chemical constituents within the wastewater effluent is dependent on several factors including the type and mass-loading of chemical inputs to the treatment process, the treatment technology employed, the duration of treatment of the wastewater, and the discharge limit, if applicable. Facilities that discharge to a POTW must treat their wastewater to meet the permit levels set by the receiving POTW for targeted contaminants such as metals and biochemical oxygen demand (BOD). Facilities that discharge wastewater directly to a receiving stream must obtain a NPDES permit, which establishes limits for similar chemical contaminants.

No data were collected for this waste stream due to dependance on factors outside of the surface finishing technology. However, organic chemical constituents resulting from the mass-loading into the treatment process are calculated and organic releases to the receiving stream are modeled in Section 3.2, Exposure Assessment.

Solid Waste. Solid wastes are generated by day-to-day surface finishing line operation and by wastewater treatment of process effluent. Some of these solid wastes are recycled, while others are sent to incineration or land disposal. The total solid waste outputs are given by the equation:

$$S_{total} = S_1 + S_2 + S_3 + S_4$$

where,

S_1	=	hazardous solid waste
S_2	=	non-hazardous solid waste
S_3	=	drummed solid or liquid waste
S_4	=	sludge from on-site wastewater treatment

These terms are discussed below.

S_1 *Hazardous solid waste.* Hazardous solid waste could include spent bath filters, solder dross, packaging or chemical container residues, and other solid waste from the process line which is contaminated with any hazardous material, as defined by the Resource Conservation and Recovery Act (RCRA). For example, lead, which is a component of the solder used in the HASL technology, is considered a hazardous solid waste (the

RCRA waste code D008 is for lead).[3] Container residue is estimated by EPA to be up to four percent of the chemicals use volume (Froiman, 1996). An industry reviewer indicated this estimate would only occur with very poor housekeeping practices and is not representative of the PWB industry. RCRA waste codes which are applicable to the surface finishing technologies are discussed in Section 4.3, Regulatory Status. Hazardous solid waste is typically sent off-site to a hazardous waste landfill for disposal or is incinerated.

S_2 *Non-hazardous solid waste.* Non-hazardous solid wastes could include any spent bath filters, packaging or chemical container residues, and other solid waste from the process line that does not contain any RCRA-defined hazardous materials listed in CFR Section 261. These wastes may be recycled or sent to off-site disposal in a landfill.

S_3 *Drummed solid or liquid waste.* This includes other liquid or solid wastes that are drummed for off-site recycling or disposal. This includes spent bath chemicals which cannot be treated on-site because they are considered hazardous or require treatment beyond what can be provided by the facility. Hazardous chemical wastes are sent to a hazardous waste treatment facility. Table 3-5 is a summary of responses indicating the presence of a RCRA listed waste and the type of container in which it was stored.

Other chemical wastes are drummed and sent out for recycling to reclaim the metal content from the solution (e.g., gold, silver, nickel, etc.). The number of responses which indicated that a bath was drummed for disposal was shown in Table 3-4.

S_4 *Sludge from on-site wastewater treatment.* Facilities were asked to report the amount of sludge generated during on-site wastewater treatment that could be attributed to surface finishing line effluents (question 1.3). Many PWB manufacturers have indicated that the amount of sludge resulting from the surface finishing process cannot be reliably estimated since effluents from various PWB manufacturing process steps are combined prior to wastewater treatment. Other factors that also influence the amount of sludge generated during wastewater treatment include the size of the facilities, the surface finishing technology used, the treatment method used, facility operating procedures, the efficiency with which bath chemicals and rinse water are used, and so on. Thus, the actual and comparative amount of sludge generated due to the choice of surface finishing technology could not be determined, nor were data available to characterize the concentrations of metals contributed by the surface finishing line.

However, many respondents did report the annual amount of sludge generated from their on-site waste treatment facility. The average sludge generated annually by the respondents to the PWB Workplace Practices Questionnaire is 214,900 pounds. The average water content of the sludge, which is typically pressed prior to disposal, ranges from 60 to 70 percent (Sharp, 1999).

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[3] It is important to note that solder dross and solder pot dumps are excluded from the RCRA definition of solid waste when they are recycled. Therefore, when they are recycled they are not considered a hazardous solid waste.

Table 3-5. RCRA Wastes and Container Types for Surface Finishing Technologies

Process Alternatives	Bath Name	No. of Baths	No. of RCRA Wastes	Open Head Drum	Close Head Drum	Others
HASL	Cleaner	12	1	0	2	0
	Microetch	25	8	0	9	4
	Flux	26	7	0	12	0
	Solder	26	7	8	6	5
	Pressure Rinse	21	2	1	1	3
Nickel/Gold	Cleaner	7	1	0	2	0
	Microetch	8	2	0	3	0
	Catalyst	5	1	0	2	0
	Acid dip	18	3	0	6	0
	Electroless. Nickel	8	0	0	3	0
	Immersion Gold	8	3	0	4	0
OSP	Cleaner	7	2	0	1	2
	Microetch	8	1	0	1	2
	OSP	7	0	0	1	1
Immersion Tin	Cleaner	5	0	0	1	0
	Immersion Tin	4	0	0	1	0

Transformations

Transformations within the surface finishing system boundary could include:

R_1 *Chemical reaction gains or losses*. This includes any chemical species consumed, transformed, or produced in chemical reactions and side reactions occurring in the process baths. Reactions and side reactions within the baths could result in either chemical losses or production of new chemicals as degradation products. Although there are almost certainly side reactions which occur, little research has been conducted to identify them when they do not obstruct the desired reactions. This is not quantified.

Material Balance

A material balance approach is often used to describe and analyze a process. The approach is based on the principle that the mass of the material inputs must equal the mass of the material outputs if the process is at steady-state (i.e., there is no accumulation of material within the process). Although the PWB Workplace Practices Questionnaire did not collect enough data to quantify every stream, the approach is a useful way to identify and organize input and output streams that cross the boundary of the system (the process in this case).

The general mass balance equation for a specific chemical is:

$$\text{Input - Output + Production - Consumption = Accumulation}$$

Since there were no chemical transformations identified, the production and consumption terms are dropped from the equation. When the system is considered to be running at steady-state, the accumulation term is equal to zero and the mass balance equation becomes:

$$\text{Inputs} = \text{Outputs}$$

The material balance for Figure 3-1 (surface finishing process line prior to wastewater treatment) includes the inputs I_1, I_2, I_3, and I_4, and the outputs P_1, A_1, A_2, W_1, W_2, W_3, S_1, S_2, and S_3.

Since the inputs must equal the outputs, the material balance for Figure 3-1 is:

$$I_1 + I_2 + I_3 + I_4 = P_1 + A_1 + A_2 + W_1 + W_2 + W_3 + S_1 + S_2 + S_3$$

or:

$$I_{total} = P_1 + A_{total} + W_{total} + S_1 + S_2 + S_3$$

The material balance for Figure 3-2 (wastewater treatment) includes the inputs W_1, W_2, and W_3, and the outputs E_1 and S_4.

Thus, the material balance equation for Figure 3-2, wastewater treatment, is:

$$W_1 + W_2 + W_3 = E_1 + S_4$$

or:

$$W_{total} = E_1 + S_4$$

These equations are presented to indicate that all the material flows have been accounted for.

3.1.3   Source and Release Information for Specific Surface Finishing Technologies

This section applies the material balance approach described previously to the individual surface finishing technologies. Each input and output is discussed as it applies to that surface finishing technology, and quantified when possible. The numbers reported in this section represent the actual responses to the PWB Workplace Practices Questionnaire, and thus, may reflect wide variations in the data corresponding to the different operating profiles of the respondents. To facilitate comparison among process alternatives and to adjust for wide variations in the data due to differences in facility size and production levels, data are presented both as reported in the PWB Workplace Practices Questionnaire, and normalized by production amounts (annual ssf of PWB produced). Values reported in this summary are average values calculated from questionnaire responses.

The limited number of responses to the questionnaire for some technologies along with differences in production levels and operating practices between facilities make it difficult to make a comparison of technologies. To facilitate a comparative evaluation, the individual technologies were modeled using a consistent production throughput in ssf of PWB produced. The modeling of the surface finishing technologies is presented in Section 4.2, Cost Analysis.

Hot Air Solder Leveling

Figure 3-3 illustrates the generic HASL process steps and typical bath sequence evaluated in the CTSA. The number and location of rinse steps shown in the figure are based on the PWB Workplace Practices Questionnaire data. Thus, Figure 3-3 describes the types and sequence of baths in a generic HASL line, but the types and sequence of baths in an actual line could vary. A detailed description of HASL process stages is presented in Section 2.1.3, Chemistry and Process Descriptions of Surface Finishing Technologies.
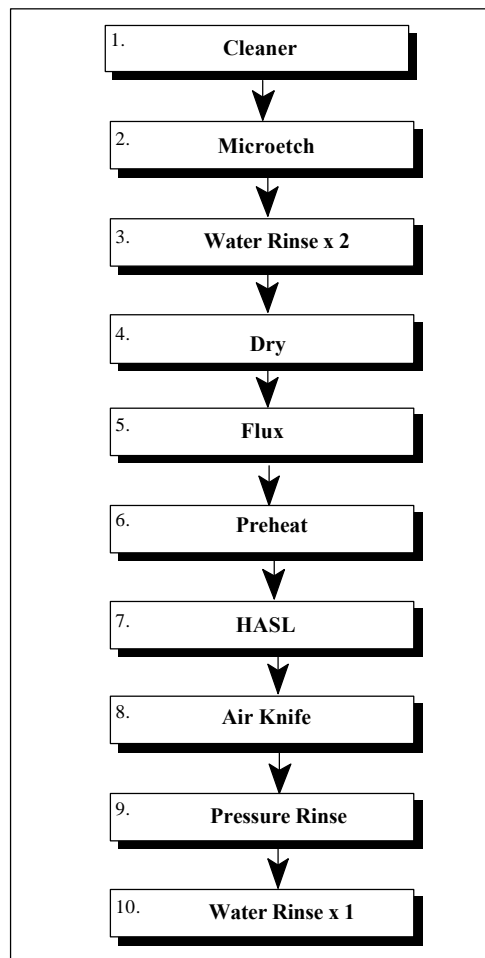

1. Cleaner
2. Microetch
3. Water Rinse x 2
4. Dry
5. Flux
6. Preheat
7. HASL
8. Air Knife
9. Pressure Rinse
10. Water Rinse x 1

Figure 3-3. Generic HASL Process Steps and Typical Bath Sequence

Water Usage (I_3) and Wastewater (W_1). Water usage data from the PWB Workplace Practices Questionnaire is presented in Table 3-1; the volume of wastewater generated was assumed to be equal to the amount of water used (I_3). Of respondents using a HASL process, 21 facilities use the conveyorized process, while 9 facilities use the non-conveyorized process. In summary:

C   Reported water usage for the facilities using the conveyorized HASL process average 1.2 million gallons per year, or about 4.9 gallons per ssf of PWB produced.

C   Reported water usage for the facilities using the non-conveyorized HASL process average 250 thousand gallons per year, or 0.97 gallons per ssf of PWB produced.

Chemical constituents and concentrations in wastewater could not be adequately characterized from questionnaire data. In the absence of quality data from industry, a model was developed to estimate the mass loading of constituents within the wastewater, resulting from drag-out, during the production of 260,000 ssf of PWB by the surface finishing process. The term drag-out refers to the process chemicals that are 'dragged' from chemical baths into the following water rinse stages, where they are washed from the board, resulting in contamination of the rinse water. The mass of chemical transferred per day to the wastewater, as well as other model results, are presented in Appendix E.

Bath Chemicals Used (I_1). Bath concentrations of individual chemical constituents are presented in Appendix B. The volume of chemicals consumed per year was determined by modeling the time it would take the generic HASL process described in Figure 3-3 to produce a specific PWB throughput. A detailed description of the process modeling is presented in Section 4.2, Cost Analysis. The number of bath replacements (calculated from the modeled time) was then multiplied by the volume of the bath to determine the volume of a bath chemical consumed per year. The mass of solder consumed per year was calculated by using an estimate of the amount of solder applied per ssf of PWB produced, then adjusted to account for solder waste. When waste solder is not routinely recycled, as much as 2,500 lbs of solder is consumed when producing 260,000 ssf of PWB. Solder consumption is discussed further in Section 5.1, Resource Conservation. Bath chemical consumption is presented Appendix G.

Cleaning Chemicals (I_4). Nine out of 129 HASL baths were reported to be cleaned using chemicals, however, data concerning the type of cleaning chemical(s) were not collected by the questionnaire. The majority of chemical flushing reported for the HASL processes was used for solder tank cleaning during bath replacement. Water is most frequently used to clean tanks prior to new bath make-up.

Spent Bath Solutions (W_2). The quantity of spent bath solution could not be determined directly from the questionnaire data. However, the volume of spent bath chemistry was calculated by determining the number of bath changes required per year and multiplying by the average volume of the process tank (see Section 4.2, Cost Analysis). The concentrations of chemical constituents within the spent bath solutions were assumed to be the same as make-up bath concentrations.

Spent bath treatment and disposal methods were presented in Table 3-4. Off-site recycling, precipitation pretreatment, and pH neutralization are reported as common treatment methods for the conveyorized HASL processes. Respondents for both the non-conveyorized, vertical process and the mixed HASL processes reported that precipitation pretreatment, pH neutralization, and off-site recycling are common treatment methods.

Evaporation From Baths (A_1). Air releases are modeled in Section 3.2, Exposure Assessment. A summary of data collected from the questionnaire is presented below:

C   For the conveyorized HASL processes, circulation pumps are used to mix all process baths except for the cleaner bath. Full enclosure and venting are the most common methods of vapor control reported by respondents for all baths and process steps.

•   For non-conveyorized HASL facilities, both panel agitation and circulation pumps are the most reported mixing methods for all baths. Venting to the outside is the prevalent form of vapor control reported, though 25 percent of the baths were reported to use bath covers.

•   Table 3-3 lists the bath surface area, volume, and bath temperature data reported by respondents to the PWB Workplace Practices Questionnaire.

Evaporation From Drying/Ovens (A_2). Air knife and oven drying occur after the microetch and HASL baths. Any solution adhering to the PWBs would be either blown off the boards and returned to the sump, or volatilized in the oven. Air emissions from air knife or oven drying were not quantified.

Chemicals Incorporated Onto PWBs (P_1). A coating of tin/lead solder is applied to the surface of PWB panels in the HASL process. The amount of solder added to the panels depends on the exposed surface area of the PWB panels being processed. The amount of solder incorporated onto a PWB was calculated at 0.0369 oz/ssf. Solder consumption is discussed further in Section 5.1, Resource Conservation.

Drummed Solid or Liquid Waste (S_3). Questionnaire respondents indicated that approximately 25 percent of HASL baths contain hazardous waste constituents as defined by RCRA. These wastes were associated by respondents with the microetch, flux, and solder baths. RCRA wastes are discussed in further detail in Section 4.3, Regulatory Status. In response to a separate question regarding spent bath treatment (see Table 3-4), 11 out of 113 HASL baths were reported by respondents to be drummed and sent off-site for recycling or disposal.

Nickel/Gold Process

Figure 3-4 depicts the generic nickel/gold process steps and typical bath sequence evaluated in the CTSA. The process baths shown in the figure represent an amalgamation of the various products offered within the nickel/gold technology category. The number and location of rinse steps displayed in the figure are based on PWB Workplace Practices Questionnaire responses. Thus, Figure 3-4 describes the types and sequence of baths in a generic nickel/gold line, but the types and sequence of process baths used by any particular facility could vary. A detailed description of the nickel/gold process is presented in Section 2.1.3, Chemistry and Process Descriptions of Surface Finishing Technologies.

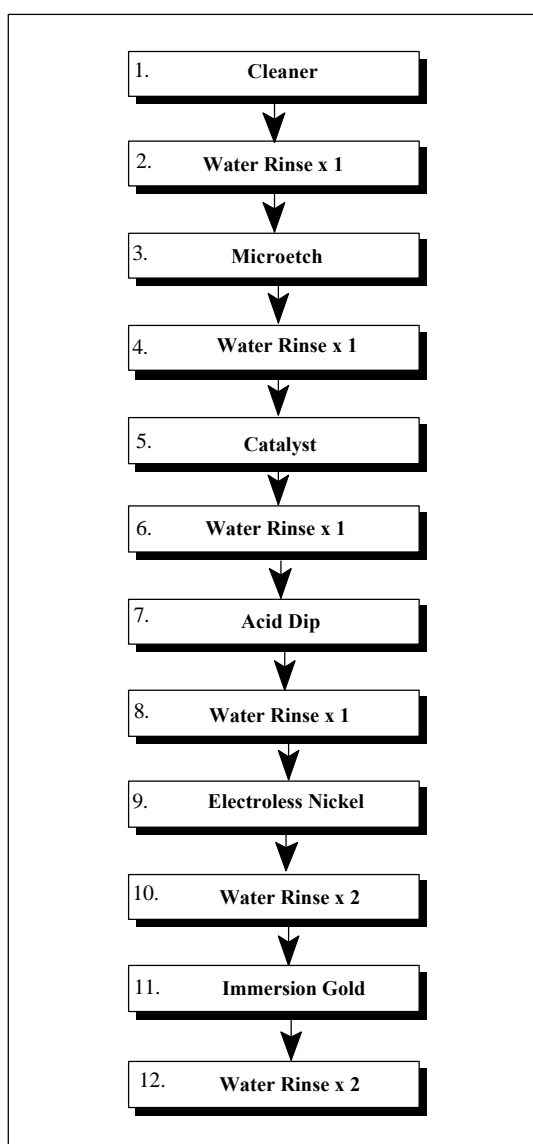|	
1.	**Cleaner**
2.	**Water Rinse x 1**
3.	**Microetch**
4.	**Water Rinse x 1**
5.	**Catalyst**
6.	**Water Rinse x 1**
7.	**Acid Dip**
8.	**Water Rinse x 1**
9.	**Electroless Nickel**
10.	**Water Rinse x 2**
11.	**Immersion Gold**
12.	**Water Rinse x 2**

Figure 3-4. Generic Nickel/Gold Process Steps and Typical Bath Sequence

Water Usage (I_3) and Wastewater (W_1). Water usage data from the PWB Workplace Practices Questionnaire is presented in Table 3-1; the volume of wastewater generated was assumed to be equal to the amount of water used (I_3). All eight respondents report using the non-conveyorized nickel/gold process. In summary:

C   Reported water usage for the facilities using the non-conveyorized nickel/gold process average 540 thousand gallons per year, or 100 gallons per ssf of PWB produced.

Chemical constituents and concentrations in wastewater could not be adequately characterized from questionnaire data. In the absence of quality data from industry, a model was developed to estimate the mass loading of constituents within the wastewater, resulting from drag-out, during the production of 260,000 ssf of PWB by the surface finishing process. The mass of chemical transferred per day to the wastewater, as well as other model results, are presented in Appendix E.

Bath Chemicals Used (I_1). Bath concentrations of individual chemical constituents are presented in Appendix B. The volume of chemicals consumed per year was determined by modeling the time it would take the generic nickel/gold process described in Figure 3-4 to produce a specific PWB throughput. A detailed description of the process modeling is presented in Section 4.2, Cost Analysis. The number of bath replacements (calculated from the modeled time) was then multiplied by the volume of the bath to determine the volume of a bath chemical consumed per year. Nickel/gold process chemical consumption is presented in Appendix G.

Cleaning Chemicals (I_4). Twelve out of 47 reported nickel/gold baths require chemicals to clean the tanks, however, data concerning the type of cleaning chemical(s) were not collected by the questionnaire. Seven of the tanks that were reported to require chemical flushing belong to electroless nickel baths. The remaining tanks requiring chemical flushing belong to baths which are not part of the generic process sequence described in Figure 3-4. Water is most frequently used to clean tanks prior to new bath make-up.

Spent Bath Solutions (W_2). The quantity of spent bath solution could not be determined directly from the questionnaire data. However, the volume of spent bath chemistry was calculated by determining the number of bath changes required per year and multiplying by the average volume of the process tank (see Section 4.2, Cost Analysis). The concentrations of chemical constituents within the spent bath solutions were assumed to be the same as make-up bath concentrations.

Spent bath treatment and disposal methods were presented in Table 3-4. Respondents for the non-conveyorized, vertical process reported that pH neutralization and precipitation pretreatment are common treatment methods. Off-site recycling was also reported as a treatment option.

Evaporation From Baths (A_1). Air releases are modeled in Section 3.2, Exposure Assessment. A summary of data collected from the questionnaire is presented below:

C   For non-conveyorized nickel/gold processes, panel agitation and circulation pumps are the most reported mixing methods for all baths. Venting to the outside is the most prevalent form of vapor control reported (33 percent), though the use of bath covers and push-pull systems are also reported.

•   Table 3-3 lists the bath surface area, volume, and bath temperature data reported by respondents to the PWB Workplace Practices Questionnaire.

Evaporation From Drying/Ovens (A_2). The nickel/gold process does not require the use of a drying oven or air knife.

Chemicals Incorporated Onto PWBs (P_1). The nickel/gold process promotes the deposition of an initial, thick layer of nickel followed by a thin, protective layer of gold onto the exposed metal surfaces of the PWB. The amount of nickel incorporated onto a PWB was calculated at 0.0337 oz/ssf, while gold was deposited at the rate of 0.0028 oz/ssf. Both nickel and gold deposition rates are discussed further in Section 5.1, Resource Conservation.

Drummed Solid or Liquid Waste (S_3). Questionnaire respondents indicated that approximately 20 percent of nickel/gold baths contain hazardous waste constituents as defined by RCRA. These wastes were associated by respondents with the microetch, acid dip, catalyst, and immersion gold baths. RCRA wastes are discussed in further detail in Section 4.3, Regulatory Status. In response to a separate question regarding spent bath treatment (see Table 3-4), two out of 55 nickel/gold baths (3.6 percent) were reported by respondents to be drummed and sent off-site for recycling. Section 5.1, Resource Conservation, presents methods commonly used to recover gold on-site.

Nickel/Palladium/Gold Process

Figure 3-5 depicts the generic nickel/palladium/gold process steps and typical bath sequence evaluated in the CTSA. The number and location of rinse steps displayed in the figure are based on PWB Workplace Practices Questionnaire responses. Thus, Figure 3-5 describes the types and sequence of baths in a generic nickel/palladium/gold line, but the types and sequence of process baths used by any particular facility could vary. A detailed description of the nickel/palladium/gold process is presented in Section 2.1.3, Chemistry and Process Descriptions of Surface Finishing Technologies.
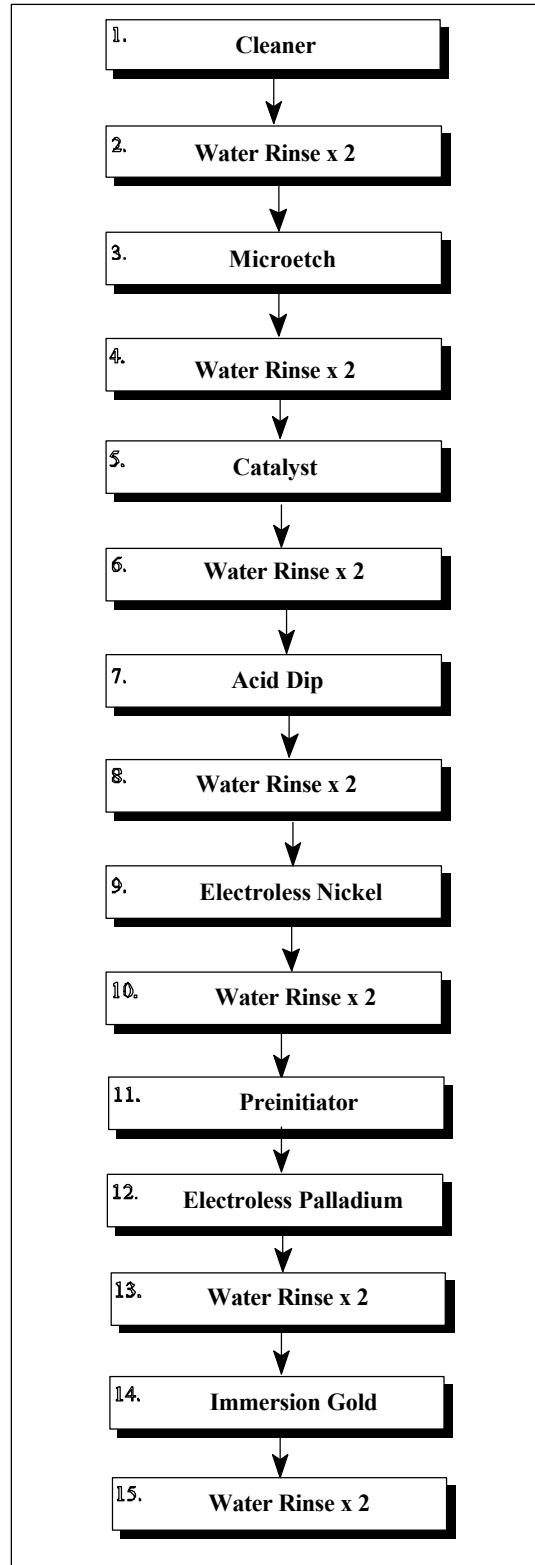
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┌─────────────────────────────────┐
│  1.        Cleaner               │
└─────────────────────────────────┘
                │
                ▼
┌─────────────────────────────────┐
│  2.     Water Rinse x 2          │
└─────────────────────────────────┘
                │
                ▼
┌─────────────────────────────────┐
│  3.        Microetch             │
└─────────────────────────────────┘
                │
                ▼
┌─────────────────────────────────┐
│  4.     Water Rinse x 2          │
└─────────────────────────────────┘
                │
                ▼
┌─────────────────────────────────┐
│  5.        Catalyst              │
└─────────────────────────────────┘
                │
                ▼
┌─────────────────────────────────┐
│  6.     Water Rinse x 2          │
└─────────────────────────────────┘
                │
                ▼
┌─────────────────────────────────┐
│  7.        Acid Dip              │
└─────────────────────────────────┘
                │
                ▼
┌─────────────────────────────────┐
│  8.     Water Rinse x 2          │
└─────────────────────────────────┘
                │
                ▼
┌─────────────────────────────────┐
│  9.     Electroless Nickel       │
└─────────────────────────────────┘
                │
                ▼
┌─────────────────────────────────┐
│  10.    Water Rinse x 2          │
└─────────────────────────────────┘
                │
                ▼
┌─────────────────────────────────┐
│  11.       Preinitiator          │
└─────────────────────────────────┘
                │
                ▼
┌─────────────────────────────────┐
│  12.   Electroless Palladium     │
└─────────────────────────────────┘
                │
                ▼
┌─────────────────────────────────┐
│  13.    Water Rinse x 2          │
└─────────────────────────────────┘
                │
                ▼
┌─────────────────────────────────┐
│  14.    Immersion Gold           │
└─────────────────────────────────┘
                │
                ▼
┌─────────────────────────────────┐
│  15.    Water Rinse x 2          │
└─────────────────────────────────┘
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Figure 3-5. Generic Nickel/Palladium/Gold Process Steps and Typical Bath Sequence

Water Usage (I_3) and Wastewater (W_1). Water usage data from the PWB Workplace Practices Questionnaire is presented in Table 3-1; the volume of wastewater generated was assumed to be equal to the amount of water used (I_3). Of the two facilities using the nickel/palladium/gold process included in this study, both report using the non-conveyorized process configuration. In summary:

C Reported water usage for the facilities using the non-conveyorized nickel/palladium/gold process average 960 thousand gallons per year, or 160 gallons per ssf of PWB produced.

Chemical constituents and concentrations in wastewater could not be adequately characterized from questionnaire data. In the absence of quality data from industry, a model was developed to estimate the mass loading of constituents within the wastewater, resulting from drag-out, during the production of 260,000 ssf of PWB by the surface finishing process. The mass of chemical transferred per day to the wastewater, as well as other model results, are presented in Appendix E.

Bath Chemicals Used (I_1). Bath concentrations of individual chemical constituents are presented in Appendix B. The volume of chemicals consumed per year was determined by modeling the time it would take the generic nickel/palladium/gold process described in Figure 3-5 to produce a specific PWB throughput. A detailed description of the process modeling is presented in Section 4.2, Cost Analysis. The number of bath replacements (calculated from the modeled time) was then multiplied by the volume of the bath to determine the volume of a bath chemical consumed per year. Nickel/palladium/gold process chemical consumption is presented in Appendix G.

Cleaning Chemicals (I_4). Eight out of 14 reported nickel/palladium/gold baths require chemicals to clean the tanks, however, data concerning the type of cleaning chemical(s) were not collected by the questionnaire. Chemical flushing was reported at least once for the microetch, acid dip, electroless nickel, electroless palladium, and immersion gold tanks. The remaining tanks requiring chemical flushing belong to baths which are not part of the generic process sequence described in Figure 3-5. Water is most frequently used to clean tanks prior to new bath make-up. Hand scrubbing was also required for tank cleaning by several of the respondents.

Spent Bath Solutions (W_2). The quantity of spent bath solution could not be determined directly from the questionnaire data. However, the volume of spent bath chemistry was calculated by determining the number of bath changes required per year and multiplying by the average volume of the process tank (see Section 4.2, Cost Analysis). The concentrations of chemical constituents within the spent bath solutions were assumed to be the same as make-up bath concentrations.

Spent bath treatment and disposal methods were presented in Table 3-4. Respondents for the non-conveyorized, vertical process reported that precipitation pretreatment was the prevalent treatment method for spent bath solutions. Drummed for off-site treatment and pH neutralization were also reported.

Evaporation From Baths (A_1). Air releases are modeled in Section 3.2, Exposure Assessment. A summary of data collected from the questionnaire is presented below:

- For non-conveyorized nickel/palladium/gold processes, panel agitation and circulation pumps are the most reported mixing methods for all baths, while the use of air sparging for the electroless nickel bath was also reported. Vapor control methods were only identified for two process baths by survey respondents. Both baths were reported to use bath covers.
- Table 3-3 lists the bath surface area, volume, and bath temperature data reported by respondents to the PWB Workplace Practices Questionnaire.

Evaporation From Drying/Ovens (A_2). The nickel/palladium/gold process does not require the use of a drying oven or air knife.

Chemicals Incorporated Onto PWBs (P_1). Layers of nickel, palladium, and gold are deposited onto the exposed metal surfaces of the PWBs through a series of chemical plating reactions. The amount of nickel incorporated onto a PWB was calculated at 0.0337 oz/ssf, palladium at 0.0015 oz/ssf, and gold at a rate of 0.0028 oz/ssf. The deposition rates of all three metals are discussed further in Section 5.1, Resource Conservation.

Drummed Solid or Liquid Waste (S_3). Questionnaire respondents indicated that none of the nickel/palladium/gold baths contain hazardous waste constituents as defined by RCRA. A detailed discussion of RCRA wastes can be found in Section 4.3, Regulatory Status. In response to a separate question regarding spent bath treatment (see Table 3-4), seven out of 14 nickel/palladium/gold baths (50 percent) were reported by respondents to be drummed and sent off-site for recycling or disposal. Section 5.1, Resource Conservation, presents methods commonly used to recover gold on-site.

Organic Solderability Preservative

Figure 3-6 depicts the generic OSP process steps and typical bath sequence evaluated in the CTSA. The process baths shown in Figure 3-6 represent an amalgamation of the various products offered within the OSP technology category. The number and location of rinse steps displayed in the figure are based on PWB Workplace Practices Questionnaire responses. Thus, Figure 3-6 describes the types and sequence of baths in a generic OSP line, but the types and sequence of OSP process baths used by any particular facility could vary. A detailed description of the OSP process is presented in Section 2.1.3, Chemistry and Process Descriptions of Surface Finishing Technologies.
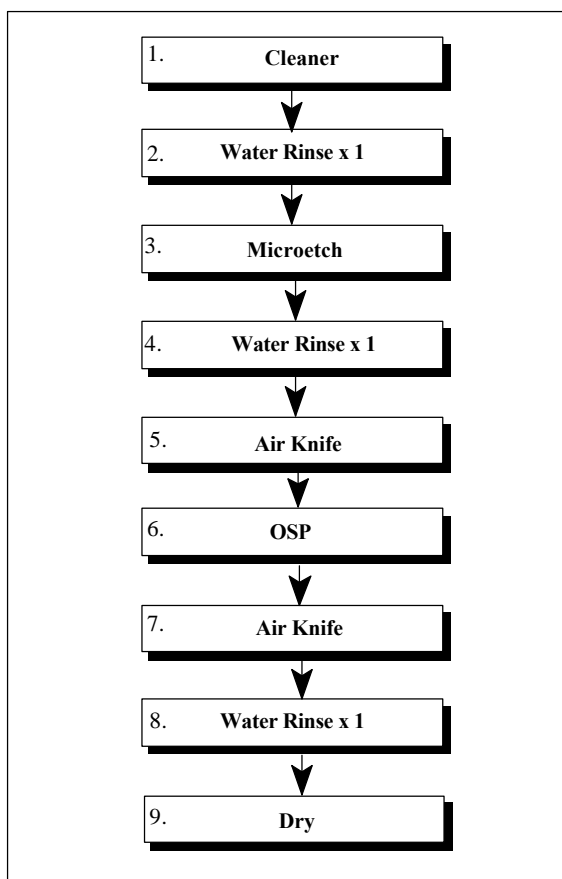
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┌─────────────────────────────────────┐
│         ┌──────────────────────┐     │
│         │ 1.      Cleaner       │     │
│         └──────────────────────┘     │
│                    ↓                  │
│         ┌──────────────────────┐     │
│         │ 2.   Water Rinse x 1  │     │
│         └──────────────────────┘     │
│                    ↓                  │
│         ┌──────────────────────┐     │
│         │ 3.     Microetch      │     │
│         └──────────────────────┘     │
│                    ↓                  │
│         ┌──────────────────────┐     │
│         │ 4.   Water Rinse x 1  │     │
│         └──────────────────────┘     │
│                    ↓                  │
│         ┌──────────────────────┐     │
│         │ 5.     Air Knife      │     │
│         └──────────────────────┘     │
│                    ↓                  │
│         ┌──────────────────────┐     │
│         │ 6.       OSP          │     │
│         └──────────────────────┘     │
│                    ↓                  │
│         ┌──────────────────────┐     │
│         │ 7.     Air Knife      │     │
│         └──────────────────────┘     │
│                    ↓                  │
│         ┌──────────────────────┐     │
│         │ 8.   Water Rinse x 1  │     │
│         └──────────────────────┘     │
│                    ↓                  │
│         ┌──────────────────────┐     │
│         │ 9.       Dry          │     │
│         └──────────────────────┘     │
└─────────────────────────────────────┘
```

Figure 3-6. Generic OSP Process Steps and Typical Bath Sequence

Water Usage (I_3) and Wastewater (W_1). Water usage data from the PWB Workplace Practices Questionnaire is presented in Table 3-1; the volume of wastewater generated was assumed to be equal to the amount of water used (I_3). Of respondents using the OSP process, five facilities use the conveyorized OSP process while five other facilities use the non-conveyorized OSP process. In summary:

C   Reported water usage for the facilities using the conveyorized OSP process average 440 thousand gallons per year, or about 14 gallons per ssf of PWB produced.
C   Reported water usage for the facilities using the non-conveyorized OSP process average 89 thousand gallons per year, or 1.9 gallons per ssf of PWB produced.

Chemical constituents and concentrations in wastewater could not be adequately characterized from questionnaire data. In the absence of quality data from industry, a model was developed to estimate the mass loading of constituents within the wastewater, resulting from drag-out, during the production of 260,000 ssf of PWB by the surface finishing process. The mass of chemical transferred per day to the wastewater, as well as other model results, are presented in Appendix E.

Bath Chemicals Used (I_1). Bath concentrations of individual chemical constituents are presented in Appendix B. The volume of chemicals consumed per year was determined by modeling the time it would take the generic OSP process described in Figure 3-6 to produce a specific PWB throughput. A detailed description of the process modeling is presented in Section 4.2, Cost Analysis. The number of bath replacements (calculated from the modeled time) was then multiplied by the volume of the bath to determine the volume of a bath chemical consumed per year. OSP process chemical consumption is presented in Appendix G.

Cleaning Chemicals (I_4). Three out of 31 OSP baths were reported to be cleaned using chemicals, however, data concerning the type of cleaning chemical(s) were not collected by the questionnaire. All of the chemical flushing reported for OSP processes was used for cleaning the OSP tank during bath replacement. Water is most frequently used to clean tanks prior to new bath make-up.

Spent Bath Solutions (W_2). The quantity of spent bath solution could not be determined directly from the questionnaire data. However, the volume of spent bath chemistry was calculated by determining the number of bath changes required per year and multiplying by the average volume of the process tank (see Section 4.2, Cost Analysis). The concentrations of chemical constituents within the spent bath solutions are assumed to be the same as make-up bath concentrations.

Spent bath treatment and disposal methods were presented in Table 3-4. Precipitation pretreatment, pH neutralization, and drummed for off-site treatment are reported as common treatment methods for the conveyorized OSP processes. Respondents for the non-conveyorized, vertical process reported that pH neutralization and precipitation pretreatment are common treatment methods.

Evaporation From Baths (A_1). Air releases are modeled in Section 3.2, Exposure Assessment. A summary of data collected from the questionnaire is presented below:

- For the conveyorized OSP processes, circulation pumps are used to mix all process wet chemistry baths. Full enclosure and venting are the most common methods of vapor control reported by respondents for all baths and process steps.
- For non-conveyorized OSP processes, both panel agitation and circulation pumps are the most reported mixing methods for all baths. Venting to the outside is the most prevalent form of vapor control reported (66 percent), though a push-pull vapor control system is also reported (33 percent).
- Table 3-3 lists the bath surface area, volume, and bath temperature data reported by respondents to the PWB Workplace Practices Questionnaire.

Evaporation From Drying/Ovens (A_2). Air knife and oven drying occur after the microetch and OSP baths. Any solution adhering to the PWBs would be either blown off the boards and returned to the sump, or volatilized in the oven. Air emissions from air knife or oven drying were not modeled.

Chemicals Incorporated onto PWBs (P_1). A thin coating of a protective organic compound is applied to the surfaces of the PWB to protect the solderability of the copper surfaces.

Drummed Solid or Liquid Waste (S_3). Questionnaire respondents indicated that approximately 15 percent of OSP baths contain hazardous waste constituents as defined by RCRA. These wastes were primarily associated by respondents with the cleaner bath. RCRA wastes are discussed in further detail in Section 4.3, Regulatory Status. In response to a separate question regarding spent bath treatment (see Table 3-4), four out of 28 OSP baths were reported to be drummed and sent off-site for recycling or disposal.

Immersion Silver Process

Figure 3-7 depicts the generic immersion silver process steps and typical bath sequence evaluated in the CTSA. The number and location of rinse steps displayed in the figure are based on PWB Workplace Practices Questionnaire responses. Thus, Figure 3-7 describes the types and sequence of baths in a generic immersion silver line, but the types and sequence of immersion silver process baths used by any particular facility could vary. A detailed description of the immersion silver process is presented in Section 2.1.3, Chemistry and Process Descriptions of Surface Finishing Technologies.
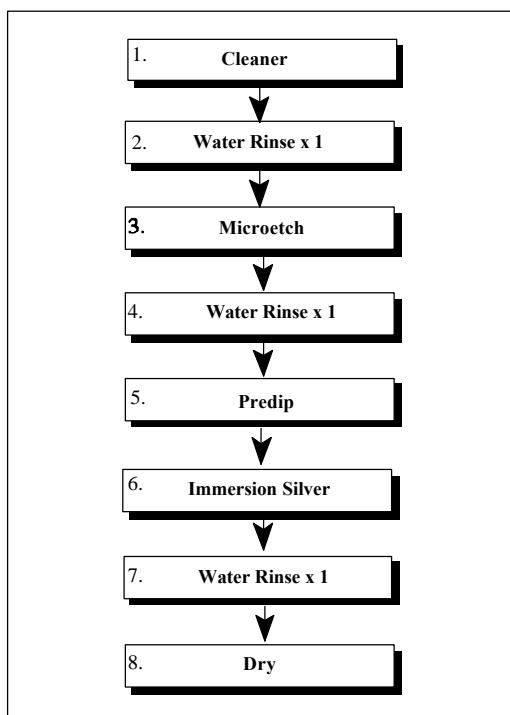
Figure 3-7. Generic Immersion Silver Process Steps and Typical Bath Sequence

Water Usage (I_3) and Wastewater (W_1). Water usage data from the PWB Workplace Practices Questionnaire is presented in Table 3-1; the volume of wastewater generated was assumed to be equal to the amount of water used (I_3). Of the two respondents using the immersion silver process, both reported using the conveyorized process configuration. In summary:

C   Reported water usage for the facilities using the conveyorized immersion silver process average 910 thousand gallons per year, or about 37 gallons per ssf of PWB produced.

Chemical constituents and concentrations in wastewater could not be adequately characterized from questionnaire data. In the absence of quality data from industry, a model was developed to estimate the mass loading of constituents within the wastewater, resulting from drag-out, during the production of 260,000 ssf of PWB by the surface finishing process. The mass of chemical transferred per day to the wastewater, as well as other model results, are presented in Appendix E.

Bath Chemicals Used (I_1). Bath concentrations of individual chemical constituents are presented in Appendix B. The volume of chemicals consumed per year was determined by modeling the time it would take the generic immersion silver process described in Figure 3-7 to produce a specific PWB throughput. A detailed description of the process modeling is presented in Section 4.2, Cost Analysis. The number of bath replacements (calculated from the modeled time) was then multiplied by the volume of the bath to determine the volume of a bath chemical consumed per year. Immersion silver process chemical consumption is presented in Appendix G.

Cleaning Chemicals (I_4). Three out of nine immersion silver baths were reported to be cleaned using chemicals, however, the type of cleaning chemical(s) were not collected by the questionnaire. The immersion silver process tanks reported to require chemical flushing prior to bath replacement included two immersion silver process tanks and one pre-dip tank. Water is most frequently used to clean tanks prior to new bath make-up.

Spent Bath Solutions (W_2). The quantity of spent bath solution could not be determined directly from the questionnaire data. However, the volume of spent bath chemistry was calculated by determining the number of bath changes required per year and multiplying by the average volume of the process tank (see Section 4.2, Cost Analysis).

The concentrations of chemical constituents within the spent bath solutions are expected to vary significantly as PWBs are processed through the bath. Some new constituents, such as copper displaced by an immersion-type plating reaction, will be present in solution, although they are not part of the original bath chemistry. While the concentrations of these chemical constituents can be significant, they are difficult to accurately estimate and will vary widely. For the purposes of this analysis, the concentrations of chemical constituents within the spent bath solutions were assumed to be the same as make-up bath concentrations.

Spent bath treatment and disposal methods were presented in Table 3-4. Precipitation pretreatment, pH neutralization, and drummed for off-site treatment are reported as common treatment methods for the conveyorized immersion silver processes.

Evaporation From Baths (A_1). Air releases are modeled in Section 3.2, Exposure Assessment. A summary of data collected from the questionnaire is presented below:

- For conveyorized immersion silver processes, circulation pumps are used to mix all process wet chemistry baths. The spraying of chemicals onto the surface of the PWB in the cleaner and microetch baths is also reported. All of the process baths were reported as fully enclosed. Only one out of ten process baths was reported to be vented to the outside.
- Table 3-3 lists bath the surface area, volume, and bath temperature data reported by respondents to the PWB Workplace Practices Questionnaire.

Evaporation From Drying/Ovens (A_2). Oven drying occurs directly after the immersion silver bath. Any solution adhering to the PWBs is volatilized during the drying of the PWBs by the oven. Air emissions resulting from oven drying were not modeled. No air knife is required by this process.

Chemicals Incorporated Onto PWBs (P_1). Silver is added to the boards in the immersion silver processes. A hydrophobic layer, formed with a co-deposited organic inhibitor, is also coated on top of the silver layer. The amount of silver incorporated onto a PWB was calculated at 0.0013 oz/ssf. Silver consumption is discussed further in Section 5.1, Resource Conservation.

Drummed Solid or Liquid Waste (S_3). Questionnaire respondents indicated that none of the immersion silver baths contain hazardous waste constituents as defined by RCRA. A detailed discussion of RCRA wastes can be found in Section 4.3, Regulatory Status. In response to a separate question regarding spent bath treatment (see Table 3-4), two out of eight immersion silver baths were reported to be drummed and sent off-site for recycling.

Immersion Tin Process

Figure 3-8 depicts the generic immersion tin process steps and typical bath sequence evaluated in the CTSA. The process baths shown in the figure represent an amalgamation of the various products offered within the immersion tin technology category. The number and location of rinse steps displayed in the figure are based on PWB Workplace Practices Questionnaire responses. Thus, Figure 3-8 describes the types and sequence of baths in a generic immersion tin line, but the types and sequence of immersion tin process baths used by any particular facility could vary. A detailed description of the immersion tin process is presented in Section 2.1.3, Chemistry and Process Descriptions of Surface Finishing Technologies.
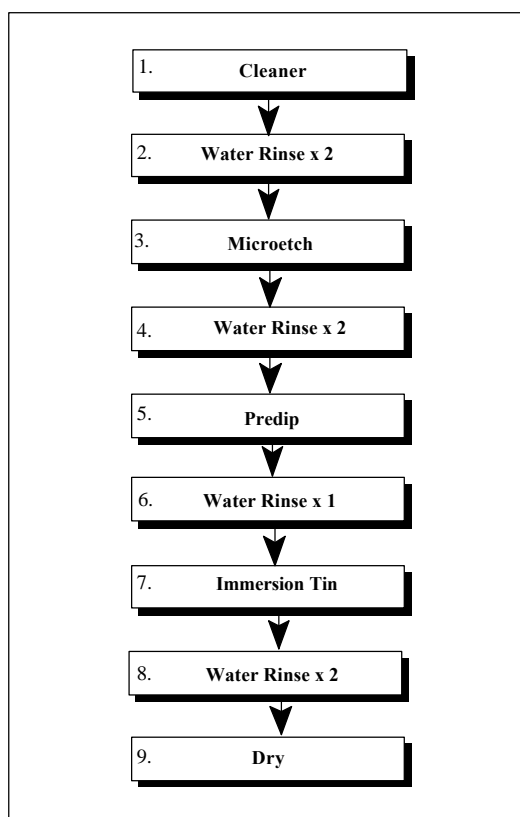
```
                    ┌─────────────────────────┐
                    │ 1.      Cleaner          │
                    └─────────────────────────┘
                                │
                                ▼
                    ┌─────────────────────────┐
                    │ 2.   Water Rinse x 2     │
                    └─────────────────────────┘
                                │
                                ▼
                    ┌─────────────────────────┐
                    │ 3.     Microetch         │
                    └─────────────────────────┘
                                │
                                ▼
                    ┌─────────────────────────┐
                    │ 4.   Water Rinse x 2     │
                    └─────────────────────────┘
                                │
                                ▼
                    ┌─────────────────────────┐
                    │ 5.      Predip           │
                    └─────────────────────────┘
                                │
                                ▼
                    ┌─────────────────────────┐
                    │ 6.   Water Rinse x 1     │
                    └─────────────────────────┘
                                │
                                ▼
                    ┌─────────────────────────┐
                    │ 7.   Immersion Tin       │
                    └─────────────────────────┘
                                │
                                ▼
                    ┌─────────────────────────┐
                    │ 8.   Water Rinse x 2     │
                    └─────────────────────────┘
                                │
                                ▼
                    ┌─────────────────────────┐
                    │ 9.       Dry             │
                    └─────────────────────────┘
```

Figure 3-8. Generic Immersion Tin Process Steps and Typical Bath Sequence

Water Usage (I_3) and Wastewater (W_1). Water usage data from the PWB Workplace
Practices Questionnaire is presented in Table 3-1; the volume of wastewater generated was
assumed to be equal to the amount of water used (I_3). Of respondents using the immersion tin
process, two facilities use the conveyorized immersion tin process while four other facilities use
the non-conveyorized process. In summary:

C   Reported water usage for the facilities using the conveyorized immersion tin process
        average 110 thousand gallons per year, or about 0.33 gallons per ssf of PWB produced.
C   Reported water usage for the facilities using the non-conveyorized immersion tin process
        average 210 thousand gallons per year, or 11 gallons per ssf of PWB produced.

        Chemical constituents and concentrations in wastewater could not be adequately
characterized from questionnaire data. In the absence of quality data from industry, a model was
developed to estimate the mass loading of constituents within the wastewater, resulting from
drag-out, during the production of 260,000 ssf of PWB by the surface finishing process. The
mass of chemical transferred per day to the wastewater, as well as other model results, are
presented in Appendix E.

Bath Chemicals Used (I_1). Bath concentrations of individual chemical constituents are presented in Appendix B. The volume of chemicals consumed per year was determined by modeling the time it would take the generic immersion tin process described in Figure 3-8 to produce a specific PWB throughput. A detailed description of the process modeling is presented in Section 4.2, Cost Analysis. The number of bath replacements (calculated from the modeled time) was then multiplied by the volume of the bath to determine the volume of a bath chemical consumed per year. Immersion tin process chemical consumption is presented in Appendix G.

Cleaning Chemicals (I_4). One out of 15 immersion tin baths were reported to be cleaned using chemicals, however, data concerning the type of cleaning chemical(s) were not collected by the questionnaire. The bath reported to require chemical flushing to clean the tank during bath replacement was the immersion tin bath. Water is most frequently used to clean tanks prior to new bath make-up.

Spent Bath Solutions (W_2). The quantity of spent bath solution could not be determined directly from the questionnaire data. However, the volume of spent bath chemistry was calculated by determining the number of bath changes required per year and multiplying by the average volume of the process tank (see Section 4.2, Cost Analysis). The concentrations of chemical constituents within the spent bath solutions were assumed to be the same as make-up bath concentrations.

Spent bath treatment and disposal methods were presented in Table 3-4. Drummed for off-site treatment and pH neutralization are reported as common treatment methods for the conveyorized immersion tin processes. Respondents for the non-conveyorized, vertical process reported that pH neutralization, precipitation pretreatment, ion exchange with on-site metal reclaim and drummed for off-site treatment are all treatment options reported by respondents.

Evaporation From Baths (A_1). Air releases are modeled in Section 3.2, Exposure Assessment. A summary of data collected from the questionnaire is presented below:

C   For the conveyorized immersion tin processes, circulation pumps are the most reported mixing methods for all baths. Full enclosure and venting are the most common methods of vapor control reported by respondents for baths other than the pre-dip bath.

•   For non-conveyorized immersion tin processes, panel agitation and circulation pumps are the most reported mixing methods for all baths. Venting to the outside is the most prevalent form of vapor control reported (33 percent), though the use of bath covers are also reported.

•   Table 3-3 lists the bath surface area, volume, and bath temperature data reported by respondents to the PWB Workplace Practices Questionnaire.

Evaporation From Drying/Ovens (A_2). Oven drying occurs directly after the immersion tin bath. Any solution adhering to the PWBs is volatilized during the drying of the PWB by the oven. Air emissions resulting from oven drying were not modeled. No air knife is required by this process.

Chemicals Incorporated Onto PWBs (P₁). A layer of metallic tin is deposited onto the PWB by the immersion tin processes. The amount of tin incorporated onto a PWB was calculated at 0.0038 oz/ssf. Tin consumption is discussed further in Section 5.1, Resource Conservation.

Drummed Solid or Liquid Waste (S₃). Questionnaire respondents indicated that none of the immersion tin baths contain hazardous waste constituents as defined by RCRA. A detailed discussion of RCRA wastes can be found in Section 4.3, Regulatory Status. In response to a separate question regarding spent bath treatment (see Table 3-4), five out of 17 immersion tin baths were reported by respondents to be drummed and sent off-site for recycling or disposal.

3.1.4   Uncertainties in the Source Release Assessment

Uncertainties and variations in the data include both gaps in knowledge (uncertainty) and variability among facilities and process alternatives. These are discussed below.

For the PWB Workplace Practices Questionnaire data:

C   There may be uncertainties due to misinterpretation of a question, not answering a question that applies to that facility, reporting inaccurate information or numbers in different units (e.g., using a mass unit to report a volumetric measurement). Also, because of a limited number of responses for the alternative processes, information more typical for that process may not be reported.

C   Variation can occur within or among process alternatives, or from difference due to varying amounts of PWB produced. According to the questionnaire database query results, data from facilities with small amounts of PWB produced often produce unrealistic results. Again, for surface finishing process alternatives with a limited number of responses, statistical summaries of the data may be precluded, and data may not be representative of most PWB facilities.

For the supplier-provided data:

C   Knowledge gaps include a lack of information on proprietary chemicals, incomplete bath composition data, and the reporting of wide ranges of chemical concentrations on a MSDS rather then specific amounts in the formulations.

C   Variation in bath chemistries and process specifications among suppliers can occur for a given process alternative. The publicly-available bath chemistry data, chemical concentrations, and supplier recommendations may not apply to a specific facility due to variation in process set-up and operation procedures.

Other uncertainties pertain to the applicability and accuracy of estimates and assumptions used in this assessment.

3.2   EXPOSURE ASSESSMENT

Evaluating exposure for the PWB CTSA involves a series of sequential steps. The first step is characterizing the exposure setting, which includes describing the physical setting and characterizing the populations of interest and their activities that may result in exposure. These are described in Section 3.2.1 for both workplace and surrounding population (ambient) exposure.

The next step is selecting a set of workplace and population exposure pathways for quantitative evaluation from the set of possible exposure pathways. This is discussed in Section 3.2.2.

Next, chemical concentrations are collected or estimated in all media where exposure could occur. For the surface finishing processes, this consists of estimating the chemical concentrations in the surface finishing baths, and performing fate and transport modeling to estimate workplace and ambient air concentrations and surface water concentrations (Section 3.2.3).

The exposure-point concentrations and other exposure parameters are combined in exposure models to estimate potential dose rates (PDRs) for all quantified pathways. These exposure models, parameter values, and resulting exposure estimates are presented in Section 3.2.4. The final step, characterizing uncertainties, is in Section 3.2.5. The exposure assessment is summarized in Section 3.2.6.

Because this CTSA is a comparative evaluation, and standardization is necessary to compare results for the surface finishing processes, this assessment focuses on a "model" (generic) PWB facility and uses aggregated data. In addition, this assessment focuses on exposure from chronic, long-term, day-to-day releases from a PWB facility, rather than short-term exposures to high levels of hazardous chemicals as there could be with a fire, spill, or periodic releases. Due to the fixed amount of resources available to the project and the lack of information to characterize such releases, high level, acute exposures could not be assessed.

3.2.1   Exposure Setting

Characterizing the exposure setting includes the following analyses:

C   characterizing the physical environment (in this case, a model PWB facility, its surface finishing process area, and the surrounding environment);
C   identifying potentially exposed workers and their activities, and any potentially exposed populations, human or ecological, that may be exposed through releases to the ambient environment from PWB facilities;
C   defining the workplace exposure scenarios to evaluate (where a *scenario* describes a specified physical setting, exposed population, and activities that may result in exposure); and
C   defining ambient exposure scenarios to evaluate.

Physical Environment

The surface finishing technologies are all wet chemistry processes consisting of a series of chemical process baths, often followed by rinse steps, through which the PWB panels are passed to apply the final surface finish. The exception is the HASL process, which combines the typical cleaning and etching chemical processes with a mechanical process of dipping a board into molten solder. (Details of each process are presented in Section 2.1, Chemistry and Process Description of Surface Finishing Technologies.)

PWB Workplace Practices Questionnaire and Performance Demonstration data, collected for 54 PWB facilities and their surface finishing process areas, were used to characterize a model PWB facility. The PWB Workplace Practices Questionnaire database includes information from 29 facilities using the HASL process, eight using nickel/gold, one using nickel/palladium/gold, nine using OSP, two using immersion silver, and five using immersion tin. Data from the questionnaire database used in the exposure models are discussed further in Section 3.2.4.

Potentially Exposed Populations

Potentially exposed populations include both workers in the PWB facilities and ecological and human populations in the vicinity of the facilities. Each of these are discussed below.

PWB Facility Employees. The questionnaire included questions about the types of workers who might be present in the surface finishing process area. These include:

C   line operators;
C   laboratory technicians;
C   maintenance workers;
C   supervisory personnel;
C   wastewater treatment operators;
C   quality inspectors; and
C   other employees.

General Population Outside the Facility. PWB facilities that are included in the PWB Workplace Practices Questionnaire and Performance Demonstration database are located throughout the U.S. This assessment estimates potential exposure to a hypothetical community living near a model PWB facility, based on a residential scenario. The primary exposure route is inhaling airborne chemicals originating from a PWB facility.

Surface Water. Exposure to ecological populations could also occur outside a PWB facility. In this assessment we evaluated exposure to aquatic organisms in a stream that receives treated wastewater from a facility.

Workplace Exposure Scenarios

A scenario describes the exposure setting, potentially exposed populations or individuals, and activities that could lead to exposure. For workplace exposures, the setting involves the surface finishing process in a PWB facility. PWB Workplace Practices Questionnaire data are used here to determine the types of workers that may be exposed and to characterize their activities. Worker activities include working in the process area, surface finishing line operation, chemical bath sampling, chemical bath additions, chemical bath replacement, rack cleaning, conveyor equipment cleaning, and filter replacement.

Working in the Process Area. Workers may inhale airborne chemicals in the surface finishing process area. Line operators are expected to have the highest inhalation exposure, because they are typically in the process area for the longest time each day. For other types of workers, their inhalation exposure would be proportional to their time spent in the process area.

Surface Finishing Line Operation. Potential for exposure during surface finishing line operation is expected to vary significantly among process methods. Non-conveyorized process configurations can be operated manually, automatically, or with a semi-automated system. In manual methods, a line operator stands at the bath and manually lowers and raises the panel racks into and out of each bath. A vertical/automated method is completely automated, where panel racks are lowered and raised into vertical tanks by a robotic arm; line operators load and unload panels from the racks. A manually-controlled vertical hoist is a semi-automated system where racks are lowered into and raised out of a series of vertical chemical baths by a line operator-controlled hoist. The hoist is controlled by a hand-held control panel attached to the hoist by a cable. The conveyorized process configuration uses an automated method where panels are transported horizontally into and out of process baths by means of a conveyor; line operators load and unload panels from the conveyor system. Based on the workplace practices data:

C   For HASL, eight out of 29 facilities reported using non-conveyorized lines, and 21 reported conveyorized lines.
C   The eight nickel/gold and one nickel/palladium/gold facilities all reported using non-conveyorized lines.
C   For facilities using OSP, four reported non-conveyorized lines and five reported conveyorized lines.
C   Both facilities using immersion silver use conveyorized lines.
C   For immersion tin, three facilities reported using non-conveyorized and two facilities use conveyorized lines.

Of the non-conveyorized systems described in the questionnaire, ten are vertical/automated systems, ten are completely manual, one uses a manually-controlled hoist, one HASL line is partly conveyorized, and two other systems were undefined. As a conservative but consistent assumption, we assumed that workers manually lower and raise panel racks for all non-conveyorized process alternatives.

Chemical Bath Sampling. Based on the questionnaire database, chemical baths are normally sampled manually by dipping/ladling. Other methods include manual sampling with a pipette or other device, and automated sampling. We assumed there could be dermal contact with bath chemicals from this activity, and quantified dermal exposure for laboratory technicians and for line operators on conveyorized lines.

Chemical Bath Additions. Methods of chemical additions, from the database, are as follows:

C   Most facilities pour chemicals directly into the bath or tank.
C   Other reported methods include manual pumping, or some combination of pumping, pouring, and/or scooping chemical formulations into a bath.

Data were collected for the length of time required to make chemical additions, and on the criteria used to determine when to add chemicals to the baths. Some facilities base chemical addition requirements on time elapsed, some on the surface area of boards processed, and some on the concentration of key constituents. For these reasons, complicated by the fact that most facilities running alternatives to HASL do not run those lines at full capacity, a typical addition frequency could not be determined. Therefore, exposure was not quantified separately for this activity.

Chemical Bath Replacement. This process includes removing the spent bath, cleaning the empty tank, and making up fresh bath solutions. In this process, a worker could be exposed to chemicals in the spent bath, on the inside walls of the emptied bath, or to chemicals in the new bath solution.

Rack Cleaning. The racks that hold PWB panels can be cleaned in a variety of ways. These include cleaning in a chemical bath on the surface finishing line or using non-chemical cleaning methods. Of the six facilities that provided information on rack cleaning, four reported using non-chemical methods, one reported using a chemical bath on the surface finishing line, and one reported shipping racks offsite for cleaning. Dermal exposure for rack cleaning is not quantified separately for this activity.

Conveyor Equipment Cleaning. Conveyor equipment cleaning involves regular equipment maintenance for conveyorized surface finishing lines. Methods include chemical baths on the surface finishing line, chemical rinse, manual scrubbing with chemicals, non-chemical cleaning, and continuous cleaning as part of the process line. It was assumed that workers could be exposed to bath chemicals during cleaning.

Filter Replacement. Filter replacement could result in exposure to the material on the filter or in the bath. Whether the pathway is significant to worker risk will depend, in part, on the chemical constituents in the bath.

Use of Personal Protective Equipment (PPE). It is assumed that the only PPE used is eye protection, and that the line operator's hands and arms may contact bath solutions. This is a

conservative but consistent assumption for all process alternatives and worker activities, particularly for dermal exposure. While many PWB facilities reported that line operators do wear gloves for various activities, the assumption that the line operator's hands and arms may contact bath solutions is intended to account for the fraction of workers who do not. For workers who do wear gloves, dermal contact exposure is expected to be negligible.

Summary of Occupational Scenarios

Surface Finishing Line Operators. In general, line operators perform several activities, as described above, including working in the surface finishing process area, surface finishing line operation, chemical bath replacement, conveyor equipment cleaning, filter replacement, chemical bath sampling, and making chemical bath additions. Some kind of local ventilation is typically used for the process line.

There are two different scenarios for line operators depending on process configuration. For non-conveyorized processes, dermal exposure could occur through routine line operation as well as bath maintenance activities. Inhalation exposure could occur throughout the time period a line operator is in the surface finishing process area. Conveyorized processes are enclosed and the line operator does not contact the bath solutions in routine line operation; he or she only loads panels at the beginning of the process and unloads them at the end of the process. For conveyorized processes, dermal exposure is primarily expected through bath maintenance activities such as bath replacement, filter replacement, bath sampling, and conveyor equipment cleaning. Because the conveyorized lines are enclosed and typically vented to the outside, inhalation exposure to line operators and other workers is much lower than for the conveyorized processes and are not presented separately.[4]

Laboratory Technicians. In general, laboratory technicians perform one activity pertaining to the surface finishing line, chemical bath sampling, in addition to working in the surface finishing process area. Bath sampling exposure is quantified separately for laboratory technicians.

Other Workers in the Surface Finishing Process Area. Other workers in the surface finishing process area may include maintenance workers, supervisory personnel, wastewater treatment operators, contract workers, and other employees. They perform activities not directly related to the surface finishing line, but typically spend some time in the surface finishing process area. Because the line operators spend the most amount of time per shift, exposure via inhalation is quantified for them (for non-conveyorized processes), and is characterized for the other employees in terms of the time spent in the process area relative to line operators.

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[4] Inhalation exposures for conveyorized process configurations were initially assumed to be negligible, and are not presented separately here. Some inhalation exposure is possible, however, during sampling and bath replacement, when the baths are opened for a short period of time. After characterizing risks from inhalation for non-conveyorized lines, inhalation exposures and risks were estimated for the subset of inhalation chemicals of concern for conveyorized lines. No chemical exposures from inhalation resulted in risks above concern levels for conveyorized lines.

Ambient Exposure Scenarios

Ambient refers to the nearby area outside of a PWB facility. As discussed in Section 3.1, Source Release Assessment, chemicals may be released to air, surface water, and/or possibly land. Receptors include members of general population living near a PWB facility and aquatic organisms, such as fish, in surface water receiving treated wastewater from a PWB facility. Exposure is also possible to animals on land or birds. The ecological assessment focused on aquatic life because much more data are available.

3.2.2   Selection of Exposure Pathways

The definition of exposure scenarios leads to selection of the exposure pathways to be evaluated. An exposure scenario may comprise one or several pathways. A complete exposure pathway consists of the following elements:

C   a source of chemical and mechanism for release;
C   an exposure point;
C   a transport medium (if the exposure point differs from the source); and
C   an exposure route.

Tables 3-6 and 3-7 present an overview of the pathway selection for workplace and surrounding population exposures, respectively. For the workplace, a potential pathway not quantified is oral exposure to vapors or aerosols. For example, oral exposure could occur if inhaled chemicals are coughed up and then swallowed.

Table 3-6. Workplace Activities and Associated Potential Exposure Pathways

Activities	Potential Pathways	Evaluation Approach and Rationale
Line Operators [a]		
Surface Finishing Line Operation	Dermal contact with chemicals in surface finishing baths.	Exposure quantified for non-conveyorized lines; the highest potential dermal exposure is expected from this activity. Exposure for conveyorized lines assumed to be negligible for this activity.
	Inhalation of vapors or aerosols from surface finishing baths.	Exposure quantified initially only for non-conveyorized lines. Exposure for conveyorized lines assumed to be much lower. [b]
Working in Process Area	Inhalation of vapors or aerosols from surface finishing baths.	Exposure quantified for non-conveyorized lines.

Activities	Potential Pathways	Evaluation Approach and Rationale
Chemical Bath Replacement; Conveyor Equipment Cleaning; Filter Replacement; Chemical Bath Sampling	Dermal contact with chemicals in bath or on filters.	Exposure quantified for conveyorized lines for all activities together (bath sampling quantified separately for laboratory technicians). Exposure not quantified separately for these activities on non-conveyorized lines.
	Inhalation of vapors or aerosols from surface finishing baths.	Not quantified separately. Included in "working in process area" for non-conveyorized lines; not quantified due to modeling limitations for conveyorized lines. [b]
Rack Cleaning	Dermal contact with chemicals on racks.	Not quantified; limited data indicate this is not performed by many facilities.
	Inhalation of vapors or aerosols from surface finishing baths.	Not quantified separately. Included in "working in process area" for non-conveyorized lines; not quantified due to modeling limitations for conveyorized lines.
Chemical Bath Additions	Dermal contact with chemicals added.	Not quantified separately from chemicals already in the baths.
	Inhalation of vapors or aerosols from surface finishing baths or while making bath additions.	Not quantified separately. Included in "working in process area" for non-conveyorized lines; not quantified due to modeling limitations for conveyorized lines.
Laboratory Technicians		
Chemical Bath Sampling	Dermal contact with chemicals in surface finishing baths.	Exposure quantified for conveyorized and non-conveyorized lines.
	Inhalation of vapors or aerosols from surface finishing baths.	Not quantified separately (included in "working in process area").
Working in Process Area	Inhalation of vapors or aerosols from surface finishing baths.	Exposure quantified for line operators for non-conveyorized lines; exposure for other workers is proportional to their exposure durations.
Maintenance Workers, Supervisory Personnel, Wastewater Treatment Operators, Contract Workers, and Other Workers		
Working in Process Area	Inhalation of vapors or aerosols from surface finishing baths.	Exposure quantified for line operators for non-conveyorized lines; exposure for other workers is proportional to their exposure durations.
	Dermal contact with chemicals in surface finishing baths.	Not quantified. [a]

[a] This assumes surface finishing line operators are the most exposed individuals and perform all direct maintenance on the surface finishing line, including filter replacement and equipment cleaning.
[b] Inhalation exposures for conveyorized process configurations were initially assumed to be negligible. Some inhalation exposure is possible, however, during sampling and bath replacement, when the baths are opened for a short period of time. After characterizing risks from inhalation for non-conveyorized lines, inhalation exposures and risks were estimated for the subset of inhalation chemicals of concern for conveyorized lines. No chemical exposures from inhalation resulted in risks above concern levels for conveyorized lines.

Table 3-7. Potential Population Exposure Pathways

Population	Potential Pathways	Evaluation Approach and Rationale
Residents Living Near a PWB Facility	Inhalation of chemicals released to air.	Exposure quantified for all potential carcinogens and any other chemical released at a rate of at least 23 kg/year.
	Contact with chemicals released to surface water directly or through the food chain.	Not evaluated. Direct exposure to surface water is not expected to be a significant pathway; modeling exposure through the food chain (e.g., someone catching and eating fish) would be highly uncertain.
	Exposure to chemicals released to land or groundwater.	Not evaluated. Not expected to be a significant pathway; modeling releases to groundwater from a landfill would be highly uncertain.
Ecological	Exposure to chemicals released to surface water.	Screening-level evaluation performed.
	Exposure to chemicals released to air or land.	Not evaluated. The human (residential) evaluation air exposure could be used as a screening-level assessment for animals living nearby. Releases directly to land are not expected, and animals are not directly exposed to groundwater.

Population exposures may occur through releases to environmental media (i.e., releases to air, water, and land). The pathways for which exposure is estimated are inhalation of chemicals released from a facility to a nearby residential area and releases of chemicals in wastewater to a receiving stream, where aquatic organisms, such as fish, may be exposed through direct contact with chemicals in surface water.

Air releases from the surface finishing process are modeled for the workplace. These modeled emission rates are used in combination with an air dispersion model to estimate air concentrations to a nearby population.

Exposures and risks from surface water are evaluated by identifying chemicals potentially released to surface water from process rinse steps following wastewater treatment. This exposure pathway is described in Section 3.2.3.

Possible sources of releases to land from surface finishing processes include bath filters and other solid wastes from the process line, chemical precipitates from baths, and sludge from wastewater treatment. These sources are discussed in Section 3.1, Source Release Assessment. Reliable characterization data for potential releases to land are not available; therefore, the exposure assessment does not estimate the nature and quantity of leachate from landfills or effects on groundwater.

3.2.3 Exposure-Point Concentrations

An exposure-point concentration is a chemical concentration in its transport or carrier medium, at the point of contact (or potential point of contact) with a human or environmental receptor. Sources of data for estimating exposure-point concentrations include monitoring data, publicly-available bath chemistry data, some proprietary bath chemistry data, and fate and transport models used to estimate air releases and air concentrations. Bath concentrations for dermal exposure were estimated from bath chemistry data. Monitoring data were used for lead from the HASL process. Fate and transport modeling were performed to estimate air concentrations for workplace and surrounding population exposures. Use of monitoring data and modeling used to estimate air concentrations are described in this section.

Monitoring Data

Air monitoring data for lead have been provided by one PWB manufacturing facility. A combination of personal monitoring for HASL line operators and air samples from the HASL process area result in an average air concentration of 0.003 mg/m^3. It should be noted that these monitoring data are limited to only one PWB manufacturer, and may vary from facility to facility. In addition, air sampling results from hand soldering operations were reported in one study (Monsalve, 1984), ranging from < 0.001 mg/m^3 to 2 mg/m^3.

Modeling Workplace Air Concentrations

Air emission models, combined with an indoor air dilution model, were used to estimate chemical air concentrations for worker inhalation exposure from PWB surface finishing lines (Robinson et al., 1997). Three air emission models were used to estimate worker exposure:

1. Volatilization of chemicals from the open surface of surface finishing tanks.
2. Volatilization of chemicals induced by air sparging.
3. Aerosol generation induced by air sparging.

The first model was applied to determine volatilization of chemicals from un-sparged baths. For the air-sparged baths, the total air emission rate for chemicals was determined by summing the releases from all three models. Modeled emission rates were then put into an indoor air dilution model to estimate workplace air concentrations. For models 1 and 2, volatilization was modeled only for those chemicals with a vapor pressure above 10^{-3} torr (a vapor pressure less than 10^{-3} torr was assumed for inorganic salts even if vapor pressure data were not available). A review of the relevant literature, descriptions of the models, and examples demonstrating the use of the models are available in the December 22, 1995, Technical Memorandum, *Modeling Worker Inhalation Exposure* (Appendix D).

Volatilization of Chemicals from the Open Surface of Surface Finishing Tanks.
Most plating tanks have a free liquid surface from which chemicals can volatilize into the workplace air. Air currents across the tank will accelerate the rate of volatilization. The

following model for evaporation of chemicals from open surfaces was used, based on EPA's Chemical Engineering Branch (CEB) Manual (U.S. EPA, 1991a):

$$F_{y,o} \approx 1{,}200\, c_{L,y}\, H_y\, A\, [D_{y,air} v_Z/() \; z)]^{0.5}$$

where,

$F_{y,o}$	=	volatilization rate of chemical y from open tanks (mg/min)
$c_{L,y}$	=	concentration of chemical y in bulk liquid (mg/L)
H_y	=	dimensionless Henry's Law Constant (H_c) for chemical y
A	=	bath surface area (m^2)
$D_{y,air}$	=	molecular diffusion coefficient of chemical y in air (cm^2/sec)
v_z	=	air velocity (m/sec)
$) z$	=	pool length along direction of air flow (m)

Concentration of chemical in bulk liquid ($c_{L,y}$) is the bath concentration. The coefficient of 1,200 includes a factor of 600 for units conversion.

Henry's constants were corrected for bath temperature. Bath temperature varies by process type and bath type; bath temperature data from the questionnaire database were determined by specific process type and bath type.

Bath surface areas used in the air modeling were determined from the questionnaire database. For non-conveyorized lines, an overall average for all baths and all processes of 422 sq in (0.280 m^2) was used. For conveyorized lines, an average was used for each type of process bath, as follows:

Conveyorized Bath Type	Average Surface Area (sq in)
Cleaner baths	1,078
Immersion silver	4,364
Immersion tin	1,436
Microetch baths	1,629
OSP	2,573
Predip baths	1,004

Some limitations of the model should be pointed out. The model was developed to predict the rate of volatilization of pure chemicals, not aqueous solutions. The model was also derived using pure chemicals. As a result, the model implicitly assumes that mass transfer resistance on the gas side is the limiting factor. The model may overestimate volatilization of chemicals from solutions when liquid-side mass transfer is the controlling factor.

Volatilization of Chemicals from Air-Sparged Surface Finishing Tanks.
Volatilization and aerosol generation from air-sparged baths were modeled only for those baths that are mixed by air sparging, as indicated in the PWB Workplace Practices Questionnaire and Performance Demonstration data; this includes the electroless nickel baths in nickel/gold and nickel/palladium/gold processes. Mixing in the baths is commonly accomplished by sparging the tank with air. The equation used for predicting the mass transfer rate from an aerated system is based on volatilization models used in research of aeration in wastewater treatment plants:

$$F_{y,s} = Q_G H_y c_{L,y} \left[1 - \exp\left(-\frac{K_{OL,y} a V_L}{H_y Q_G} \right) \right]$$

where,

$F_{y,s}$ = mass transfer rate of chemical y out of the system by sparging (mg/min)
Q_G = air sparging gas flow rate (L/min)
H_y = dimensionless Henry's Law Constant (H_C) for chemical y
$c_{L,y}$ = concentration of chemical y in bulk liquid (mg/L)
$K_{OL,y}$ = overall mass transfer coefficient for chemical y (cm/min)
a = interfacial area of bubble per unit volume of liquid (cm^2/cm^3)
V_L = volume of liquid (cm^3)

Data for the sparging air flow rate (Q_G) come from information supplied by a PWB manufacturer.

Aerosol Generation from Air-Sparged Surface Finishing Tanks. Aerosols or mists are also potentially emitted from process baths. This was estimated for electroless nickel baths in nickel/gold and nickel/palladium/gold processes. The rate of aerosol generation has been found to depend on the air sparging rate, bath temperature, air flow rate above the bath, and the distance between bath surface and the tank rim. The following equation is used to estimate the rate of aerosol generation (Berglund and Lindh, 1987):

$$R_A = \left[5.5 x 10^{-5} (Q_G / A) + 0.01 \right] F_T\ F_A\ F_D$$

where,

R_A = aerosol generation rate (ml/min/m^2)
Q_G = air sparging gas flow rate (cm^3/min)
A = bath surface area (m^2)
F_T = temperature correction factor
F_A = air velocity correction factor
F_D = distance between the bath surface and tank rim correction factor

The emission of contaminants resulting from aerosols depends on both the rate of aerosol generation and the concentration of contaminants in the aerosol. The following equation is used to estimate contaminant emission (flux) from aerosol generation:

$$F_{y,a} = \frac{M_I}{M_b} f_{IE} F_{y,s}$$

where,

$F_{y,a}$	=	rate of mass transfer from the tank to the atmosphere by aerosols (mg/min)
f_{IE}	=	fraction of bubble interface ejected as aerosols (dimensionless)
M_I	=	mass of contaminant at the interface (mg)
M_b	=	mass of contaminant in gas bubble (mg)

The literature on aerosol generation indicates that the typical size of aerosols is one to ten microns; this is important to note because particles in this range are more inhalable. Larger sized particles tend to fall back into baths rather than remaining airborne and dispersing throughout the room.

Calculation of Chemical Concentration in Workplace Air from Emission Rates. For unsparged baths, the total emission rate is equal to $F_{y,o}$ calculated by the first equation. For sparged baths, the total emission rate is equal to $F_{y,o} + F_{y,s} + F_{y,a}$, as calculated by the three equations described above. The indoor air concentration is estimated from the total emission rate using the following equation (U.S. EPA, 1991a):

$$C_y = F_{y,T}/(Q\,k)$$

where,

C_y	=	workplace contaminant concentration (mg/m^3)
$F_{y,T}$	=	total emission rate of chemical from all sources (mg/min)
Q	=	ventilation air flow rate (m^3/min)
k	=	dimensionless mixing factor

The CEB Manual commonly uses values of the ventilation rate (Q) from 500 cubic feet per minute (cfm) to 3,500 cfm; a ventilation rate for surface finishing lines of 13.6 m^3/min (480 cfm) was determined by taking the 10th percentile air flow rates from the facility questionnaire database for general ventilation. An average room volume of 505 m^3 (18,200 ft^3) was determined by assuming a ten foot room height and using the average room size from the questionnaire database. The combination of room volume and ventilation rate is equivalent to an air turnover rate of 0.026 per minute (1.56 per hour). The mixing factor (k) could be used to account for slow and incomplete mixing of ventilation air with room air; however, a value of 1.0 was used for this factor consistent with the assumption of complete mixing.

Other assumptions pertaining to these air models include the following:

C   Deposition on equipment, condensation of vapors, and photodegradation are negligible.
C   Incoming air is contaminant-free.
C   The concentration of contaminant at the beginning of the day is zero.

C   As much air enters the room as exits through ventilation (mass balance).

C   Room air and ventilation air mix ideally.

Sensitivity Analysis. Model sensitivity and uncertainty was examined for the making holes conductive (MHC) project (U.S. EPA, 1998b) using Monte Carlo analysis, with the air transport equations outlined above, and probability distributions for each parameter based on data from the PWB Workplace Practices Questionnaire. The analysis was conducted using a Monte Carlo software package (Crystal Ball™, Decisioneering, Inc., 1993) in conjunction with a spreadsheet program. Because the same models are used for this surface finishing evaluation, and the model facility is similar to that developed for MHC, the results of this sensitivity analysis are relevant to surface finishing air modeling as well.

The sensitivity analysis suggested that a few parameters are key to modeling chemical emissions from PWB tanks. These key parameters are air turnover rate, bath temperature, chemical concentration in the bath, and H_C. The air turnover rate assumption contributes most to overall model variance. The chemical bath concentration and bath temperature also contribute variance to the model, but are less important than air turnover rate. This statement is supported by the fact that relatively accurate information is available on their distributions. H_C appears to be least important of the four, but may have more variability associated with it. The models appear to be largely indifferent to small changes in most other parameters.

Modeled emission rates and workplace air concentrations are presented in Table 3-8.

Table 3-8. Results of Workplace Air Modeling

Chemical [a]	Total Emission Rate ($F_{y,T}$) (mg/min)	Workplace Air Conc. (Cy) (mg/m³)	Federal OSHA and/or NIOSH Permissible Inhalation Exposure Limits (mg/m³) [b]
HASL, Non-conveyorized			
1,4-Butenediol	9.8	0.75	none
Alkylaryl sulfonate	0.018	0.0014	NR
Arylphenol	0.0060	4.6E-04	NR
Ethylene glycol	12	0.94	no OSHA PEL or NIOSH REL
Ethylene glycol monobutyl ether	120	8.9	NIOSH REL: 24 (5 ppm) OSHA PEL: 240 (50 ppm)
Hydrochloric acid	0.89	0.068	NIOSH REL, C: 7 (5 ppm) OSHA PEL, C: 7 (5 ppm)
Hydrogen peroxide	5.2	0.40	NIOSH REL: 1.4 (1 ppm) OSHA PEL 1.4 (1 ppm)
Phosphoric acid	1.5	0.12	NIOSH REL: 1, STEL: 3 OSHA PEL: 1
Nickel/Gold, Non-conveyorized			
Aliphatic acid A	77	5.9	NR
Aliphatic acid B	5.4E-04	4.1E-05	NR
Aliphatic acid E	100	7.8	NR

Chemical [a]	Total Emission Rate ($F_{y,T}$) (mg/min)	Workplace Air Conc. (Cy) (mg/m³)	Federal OSHA and/or NIOSH Permissible Inhalation Exposure Limits (mg/m³) [b]
Aliphatic dicarboxylic acid A	0.10	0.0080	NR
Aliphatic dicarboxylic acid C	0.049	0.0038	NR
Alkyldiol	22	1.6	NR
Ammonia compound B	0.025	0.0019	NR
Ammonium hydroxide	1.2	0.094	none
Hydrochloric acid	26	2.0	NIOSH REL, C: 7 (5 ppm) OSHA PEL, C: 7 (5 ppm)
Hydrogen peroxide	3.8	0.29	NIOSH REL: 1.4 (1 ppm) OSHA PEL: 1.4 (1 ppm)
Inorganic metallic salt A	3.1E-05	2.4E-06	NR
Inorganic metallic salt B	2.1E-03	1.6E-04	NR
Inorganic metallic salt C	2.2E-05	1.7E-06	NR
Malic acid	0.22	0.017	none
Nickel sulfate	0.55	0.042	NIOSH REL, Ca: 0.015 OSHA PEL: 1
Phosphoric acid	1.2	0.092	NIOSH REL: 1, STEL: 3 OSHA PEL: 1
Potassium compound	1.0	0.079	NR
Sodium hypophosphite	0.64	0.048	none
Urea compound B	7.6E-04	5.8E-05	NR
Nickel/Palladium/Gold, Non-conveyorized			
Aliphatic acid B	5.6E-04	4.2E-05	NR
Aliphatic acid E	140	11	NR
Aliphatic dicarboxylic acid A	0.11	0.0082	NR
Aliphatic dicarboxylic acid C	0.051	0.0039	NR
Alkyldiol	22	1.7	NR
Ammonia compound B	0.026	0.0020	NR
Ammonium hydroxide	2.0	0.16	none
Ethylenediamine	0.064	0.0048	NIOSH REL: 25 (10 ppm) OSHA PEL: 25 (10 ppm)
Hydrochloric acid	28	2.1	NIOSH REL, C: 7 (5 ppm) OSHA PEL, C: 7 (5 ppm)
Hydrogen peroxide	3.7	0.28	NIOSH REL: 1.4 (1 ppm) OSHA PEL: 1.4 (1 ppm)
Inorganic metallic salt B	0.0021	1.6E-04	NR
Malic acid	0.23	0.018	none
Nickel sulfate	0.90	0.068	NIOSH REL, Ca: 0.015 OSHA PEL: 1
Phosphoric acid	1.2	0.092	NIOSH REL: 1, STEL: 3 OSHA PEL: 1
Potassium compound	1.1	0.082	NR

Chemical [a]	Total Emission Rate ($F_{y,T}$) (mg/min)	Workplace Air Conc. (Cy) (mg/m^3)	Federal OSHA and/or NIOSH Permissible Inhalation Exposure Limits (mg/m^3) [b]
Propionic acid	26	2.0	NIOSH REL: 30 (10 ppm) STEL: 45 (15 ppm)
Sodium hypophosphite	0.85	0.065	none
Urea compound B	0.0015	1.2E-04	NR
OSP, Non-conveyorized			
Acetic acid	74	5.6	NIOSH REL: 25 (10 ppm), STEL: 37 (15 ppm) OSHA PEL: 25 (10 ppm)
Arylphenol	0.0059	4.5E-04	NR
Ethylene glycol	23	1.7	no OSHA PEL or NIOSH REL
Hydrochloric acid	2.0	0.15	NIOSH REL, C: 7 (5 ppm) OSHA PEL, C: 7 (5 ppm)
Hydrogen peroxide	1.8	0.14	OSHA PEL, NIOSH REL: 1.4 (1 ppm)
Phosphoric acid	1.2	0.092	NIOSH REL: 1, STEL 3 OSHA PEL: 1
Immersion Tin, Non-conveyorized			
Aliphatic acid D	27	2.1	NR
Alkylaryl sulfonate	0.026	0.0020	NR
Cyclic amide	22	1.7	NR
Hydrochloric acid	0.090	0.069	NIOSH REL, C: 7 (5 ppm) OSHA PEL, C: 7 (5 ppm)
Hydroxy carboxylic acid	37	2.8	NR
Phosphoric acid	0.74	0.056	NIOSH REL: 1, STEL: 3 OSHA PEL: 1
Urea compound C	250	19	NR

[a] Only chemicals with calculated values are presented. A number was not calculated for a chemical if its vapor pressure is below the 1 x 10^{-3} torr cutoff and it is not used in any air-sparged bath. For these chemicals, air concentrations are expected to be negligible.

[b] Source: NIOSH, 1999. RELs and/or PELs for proprietary chemicals are not presented in order to protect confidential chemical identities. Notes about these values follow:

NIOSH REL: Recommended exposure limit, a time-weighted average (TWA) concentrations for up to a 10-hour workday during a 40-hour workweek.

OSHA PEL: The OSHA permissible exposure limits, as found in Tables Z-1, Z-2, and Z-3 of the OSHA General Industry Air Contaminants Standard (29 CFR 1910.1000). Unless noted otherwise, PELs are TWA concentrations that must not be exceeded during any 8-hour workshift of a 40-hour workweek.

STEL: A short-term exposure limit; unless noted otherwise, this is a 15-minute TWA exposure that should not be exceeded at any time during a workday.

C: A ceiling REL or PEL is designated by "C"; unless noted otherwise, the ceiling value should not be exceeded at any time.

Ca: Any substance that NIOSH considers to be a potential occupational carcinogen is designated by the notation "Ca."

Note: The numeric format used in these tables is a form of scientific notation, where the "E" replaces the " x 10$^{…}$". Scientific notation is typically used to present very large or very small numbers. For example, 1.2E-04 is the same as 1.2 x 10^{-4}, which is the same as 0.00012 in common decimal notation.

Modeling Air Concentrations for Population Exposure

The following approach was used for dispersion modeling of air emissions from a single facility:

C   The Industrial Source Complex Long Term ISC(2)LT model was used from the Risk*Assistant™ software program.
C   A building (release) height of 3 meters was assumed.
C   An area source with dimensions of 10 x 10 m was assumed.
C   Meteorological data for Oakland, California, Denver, Colorado, and Phoenix, Arizona were used. (PWB facilities are located throughout the U.S., and many are in Southern California. These three areas give the highest modeled concentrations around a facility for any available city data in the model.)
C   Regulatory default values were used for other model parameters. (These are model defaults pertaining to plume rise, stack-tip downwash, buoyancy-induced dispersion, wind profile exponents, vertical temperature gradient, and buildings adjacent to the emission source.)
C   An urban mode setting was used. (The setting can be either rural or urban. The urban setting is appropriate for urban areas or for large facilities.)
C   Because of the short time expected for chemical transport to nearby residents, chemical degradation was not taken into account.
C   A standard polar grid[5] with 36 vector directions and one distance ring (at 100m) was used; the highest modeled air concentration in any direction at 100 meters was used to estimate population exposure.

An average emission rate-to-air concentration factor of 2.18×10^{-6} min/m^3 was determined using model results for the three locations. This factor was multiplied by the total emissions rate for each chemical (in mg/min) to yield air concentrations at the receptor point, in units of mg/m^3. The emission rates calculated for workplace inhalation exposures (Table 3-8) are used for the source emission rates to ambient air. Except for the carcinogen, inorganic metallic salt A, ambient air concentrations are not reported for those chemicals with facility emission rates less than 23 kg/year (44 mg/min), which is a screening threshold typically used by EPA.[6] In addition, ambient air concentrations for lead were estimated, based on this air dispersion model and HASL workplace air monitoring data. Results of ambient air modeling are presented in Table 3-9.

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[5] A polar grid is a coordinate system that describes the location of a point by means of direction and distance in relation to a central point (e.g., two miles northeast of the center). In the model, a series of regularly-spaced concentric distance rings are defined at chosen intervals along with a defined number of direction vectors (e.g., north, south, east, west, northeast, northwest, southeast, and southwest would be eight directions).

[6] Under conservative assumptions, inhalation exposure to fugitive releases less than 23 kg/yr result in exposures of less than 1 mg/yr for an individual.

Table 3-9. Results of Ambient Air Modeling

Chemical	Emission Rate [a] (mg/min)	Air Concentration [b] (mg/m^3)
HASL, Non-conveyorizd		
Ethylene glycol monobutyl ether	120	2.55E-04
Lead	0.039 [c]	9.0E-08
HASL, Conveyorized		
Ethylene glycol monobutyl ether	230	5.05E-04
Lead	0.039 [c]	9.0E-08
Nickel/Gold, Non-conveyorized		
Aliphatic acid A	77	1.68E-04
Aliphatic acid E	100	2.22E-04
Inorganic metallic salt A	3.12E-05	6.81E-11
Nickel/Palladium/Gold, Non-conveyorized		
Aliphatic acid E	140	3.06E-04
OSP, Non-conveyorized		
Acetic acid	74	1.62E-04
OSP, Conveyorized		
Acetic acid	280	6.15E-04
Ethylene glycol	46	9.94E-05
Immersion Tin, Non-conveyorized		
Urea compound C	250	5.40E-04
Immersion Tin, Conveyorized		
Aliphatic acid D	67	1.46E-04
Cyclic amide	53	1.16E-04
Hydroxy carboxylic acid	90	1.96E-04
Urea compound C	610	1.32E-03

[a] Only those chemicals with an emission rate of at least 23 kg/year (44 mg/min) are listed. Immersion silver had no modeled emission rates above this cut-off.

[b] The numeric format used in this column is a form of scientific notation, where "E" replaces the " x 10^x. Scientific notation is typically used to present very large or very small numbers. For example, 1.2E-04 is the same as 1.2 x 10^{-4}, which is the same as 0.00012 in common decimal notation.

[c] Based on air monitoring data from one facility, with an average workplace air concentration of 0.003 mg/m^3.

Surface Water

PWB manufacturers typically combine wastewater effluent from the surface finishing process line with effluent from other PWB manufacturing processes prior to on-site wastewater pretreatment. The pretreated wastewater is then discharged to a POTW. Consequently, characterizing the process wastewater has been problematic. Because many of the chemical constituents expected in the wastewater of the surface finishing process are also found in other PWB manufacturing processes, testing data obtained from industry was not sufficient to characterize what portion of the overall wastewater contamination was actually attributable to the operation of the surface finishing process. Therefore, a model was developed to estimate environmental releases to surface water for chemical constituents and concentrations in the wastewater as a result of the operation of the surface finishing process alone.

In the absence of quality data from industry, this model was developed using laboratory testing to determine the amount of drag-out from a wet chemistry process involving PWBs and the amount of chemical disposed through bath replacement. The MHC process, which is similar in operation to the surface finishing process, was used as the basis for the model because of the availability of chemical formulation data at time of development. The term drag-out refers to the process chemicals that are 'dragged' (lost) from chemical baths into the following water rinse stages, during the processing of PWB panels through the surface finishing line. Residual process chemicals are washed from the surface of the PWB by the rinse water stages resulting in contamination of the rinse water. Industry has estimated that up to 95 percent of the chemical contamination in the wastewater is attributable to drag-out (the remaining contamination results from spent bath treatment and bath maintenance practices). The drag-out model is given by the following linear regression equation:

$$DO = 18 + 201 \text{ (SIZE)} - 60.1 \text{ (ELCTRLS)} + 73 \text{ (WR/DT)} - 20.9 \text{ (ALK)} + 26 \text{ (HOLES)} + 26.1 \text{ (WR)} - 0.355 \text{ (DT)}$$

where,

DO	=	drag-out from bath, ml/m^2
SIZE	=	board area, m^2
WR	=	withdraw rate, m/sec
DT	=	drain time, sec
ALK	=	1 if the bath is an alkaline cleaner bath and = 0 otherwise
HOLES	=	1 if the board is drilled and = 0 for undrilled boards (we assumed that all boards were drilled)
ELCTRLS	=	1 if the bath is an electroless copper bath and = 0 otherwise

The model was used to estimate the mass loading of constituents to the wastewater resulting from drag-out during the production of 260,000 ssf of PWB by the surface finishing process, by the following equation:

$$MD_{ij} \;=\; P * C_{ij} * DO_{ij} / 1,000,000$$

where,

MDij = drag-out mass of constituent I from bath j, g/d
P = PWB production rate, m^2/day
Cij = concentration of constituent I in bath j, mg/L

The amount of chemical going to wastewater from bath replacement was calculated by:

$$Mbij = Fj/T * Vj * Cij / 1,000$$

where,
MBij = mass of constituent I from dumping bath j, g/d
Fj = replacement frequency for bath j, times/yr
T = operating time (from cost model, total production time minus down time), days/yr
V = volume of bath j, L

For non-conveyorized lines, the total mass per day going to wastewater is the sum of drag-out mass and bath dumping mass for the constituent in all baths:

$$Mi = \sum_{j=1}^{n}(MDij + MBij)$$

where,
Mi = total mass of constituent i going to wastewater, g/d, from all baths j containing constituent i

Because conveyorized lines are designed to operate with minimal drag-out, and the drag-out model was developed only for vertical configurations, bath replacement alone was considered in estimating chemical amounts to wastewater. For conveyorized lines,

$$Mi = \sum_{j=1}^{n} MBij$$

A detailed description of the model, along with the methods of model development, validation and testing, and model limitations, are presented in *Prediction of Water Quality from Printed Wiring Board Processes* (Robinson et al., 1999) and Appendix E.

Preliminary in-stream concentrations were then calculated from the mass loading by considering dilution in the receiving stream and assuming no treatment, by:

$$Ci,_{SW} = 1000 \, Mi / (Q_{SW} + Q_{WW})$$

where,
$Ci,_{SW}$ = preliminary surface water concentration of constituent i, assuming no treatment, mg/L
Q_{SW} = surface water flow rate, L/day
Q_{WW} = wastewater flow rate, L/day

For surface water flow, we used a rate of 13.3 million liters/day. This is the 10^{th} percentile low flow rate (7Q10) for the distribution of streams associated with facilities with the Electronic Components Manufacture SIC code. This type of flow rate is typically used by EPA for comparisons of screening-level estimates of in-stream chemical concentrations versus concern concentrations (CCs) for aquatic species.

These concentrations were then screened against CCs for toxicity to aquatic life (CCs are discussed in Section 3.3.3 and Appendix H). For any chemicals with preliminary in-stream concentrations exceeding CCs, a typical treatment efficiency was determined. For this purpose, it was assumed that wastewater treatment consisted of primary treatment by gravitational settling followed by complete-mix activated sludge secondary treatment and secondary settling (clarification), as typically employed at POTWs. Treatment efficiencies were estimated on a chemical-by-chemical basis using a combination of readily available data on the chemical or close structural analogs and best professional judgment. Information sources included EPA's Treatability Database, the Environmental Fate Data Base (Syracuse Research Corp., updated periodically), the *Handbook of Environmental Degradation Rates* (Howard et al., 1991), wastewater engineering handbooks such as Metcalf and Eddy, and various journal articles from the published literature.

Treatment efficiencies were then applied to the chemical concentrations, and revised in-stream concentrations were calculated. Select inorganic constituents that are targeted by industry for treatment, such as metals, were assumed to be treated effectively by on-site treatment to required effluent levels. These metals are not included in the surface water evaluation. (Pretreatment is discussed further in Section 6.2, Control Technologies.) Results for chemicals, excluding metals, where the initial stream concentration (without treatment) exceeded the CC for that chemical are presented in Table 3-10. Full results are presented in Appendix E.

Table 3-10. Estimated Releases to Surface Water Following Treatment

Chemical [a]	Conc. in Wastewater Released to Stream (mg/L)	Stream Conc. w/o POTW Treatment (mg/L)	Treatment Efficiency (%)	Stream Conc. after POTW Treatment (mg/L)
HASL, Non-conveyorized				
1,4-Butenediol	49	0.10	90	0.010
Alkylaryl sulfonate	2.3	0.0049	0	0.0049
Citric acid	94	0.20	93	0.014
Ethylene glycol monobutyl ether	71	0.15	90	0.015
Hydrogen peroxide	195	0.41	90	0.041
Potassium peroxymonosulfate	390	0.82	90	0.082
HASL, Conveyorized				
1,4-Butenediol	23	0.076	90	0.0076
Alkylaryl sulfonate	1.0	0.0035	0	0.0035
Citric acid	42	0.14	93	0.0099

Chemical [a]	Conc. in Wastewater Released to Stream (mg/L)	Stream Conc. w/o POTW Treatment (mg/L)	Treatment Efficiency (%)	Stream Conc. after POTW Treatment (mg/L)
Ethylene glycol monobutyl ether	32	0.11	90	0.011
Hydrogen peroxide	90	0.30	90	0.030
Potassium peroxymonosulfate	180	0.61	90	0.061
Nickel/Gold, Non-conveyorized				
Hydrogen peroxide	62	0.045	90	0.0045
Substituted amine hydrochloride	97	0.070	80	0.014
Nickel/Palladium/Gold, Non-conveyorized				
Hydrogen peroxide	36	0.034	90	0.0034
Substituted amine hydrochloride	55	0.053	80	0.011
OSP, Non-conveyorized				
Alkylaryl imidazole	200	0.33	90	0.033
Hydrogen peroxide	110	0.18	90	0.018
OSP, Conveyorized				
Alkylaryl imidazole	75	0.18	90	0.018
Hydrogen peroxide	61	0.15	90	0.015
Immersion Silver, Conveyorized				
1,4-Butenediol	48	0.029	90	0.0029
Fatty amine	7.7	0.0047	95	0.00023
Hydrogen peroxide	430	0.26	90	0.026
Immersion Tin, Non-conveyorized				
Alkylaryl sulfonate	1.2	0.0021	0	0.0021
Citric acid	660	1.2	93	0.082
Ethylene glycol monobutyl ether	36	0.064	90	0.0064
Potassium peroxymonosulfate	200	0.36	90	0.036
Quantenary alkylammonium chlorides	42	0.074	90	0.0074
Thiourea	170	0.30	90	0.030
Urea compound C	35	0.062	90	0.0062
Immersion Tin, Conveyorized				
Potassium peroxymonosulfate	68	0.041	90	0.0041

[a] This includes any chemicals, except metals, where the initial stream concentration (without treatment) exceeded the CC for that chemical. Metals are not included; it was assumed that metals are targeted for effective on-site treatment.

3.2.4　Estimating Potential Dose Rates

This section contains information on exposure models, parameter values, and resulting exposure estimates for potential workplace and population exposures. Data on frequency and duration of most activities were derived from the PWB Workplace Practices Questionnaire database, Product Data Sheets from chemical suppliers (e.g., bath change out rates), and the process simulation model (e.g., days of process operation). The general models for calculating inhalation and dermal potential dose rates are discussed below.

Inhalation Exposures

The general model for inhalation exposure to workers is from CEB (U.S. EPA, 1991a):

$$I = (Ca)(IR)(ET)$$

where,

I　　=　　daily inhalation potential dose rate (mg/day)
Ca　=　　airborne concentration of substance (mg/m^3)
　　　　　(Note: this term is denoted "C_y" in air modeling equation in Section 3.2.3.)
IR　=　　inhalation rate (m^3/hr)
ET　=　　exposure time (hr/day)

Daily exposures are averaged over a lifetime (70 years) for carcinogens, and over the exposure duration (e.g., 25 years working in a facility) for non-carcinogens.[7] The following equations are used to estimate average daily doses for inhalation:

$$LADD = (I)(EF)(ED)/[(BW)(AT_{CAR})]$$
$$ADD = (I)(EF)(ED)/[(BW)(AT_{NC})]$$

where,

LADD　　　=　　lifetime average daily dose (mg/kg-day) (for carcinogens)
ADD　　　　=　　average daily dose (mg/kg-day) (for non-carcinogens)
I　　　　　　=　　daily inhalation potential dose rate (mg/day)
EF　　　　　=　　exposure frequency (days/year)
ED　　　　　=　　exposure duration (years)
BW　　　　　=　　body weight (kg)
AT_{CAR}　　　=　　averaging time for carcinogenic effects (days)
AT_{NC}　　　=　　averaging time for non-carcinogenic effects (days)

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[7] Different averaging times are used for characterizing risk for carcinogenic and non-carcinogenic effects. For carcinogenic agents, because even a single incidence of exposure is assumed to have the potential to cause cancer throughout an individual's lifetime, the length of exposure to that agent is averaged over a lifetime. An additional factor is that the cancer latency period may extend beyond the period of working years before it is discernible. For chemicals exhibiting non-cancer health effects from chronic (longer-term) exposure, where there is an exposure threshold (a level below which effects are not expected to occur); only the time period when exposure is occurring is assumed to be relevant and is used as the averaging time.

Parameter values for estimating workers' potential dose rates from inhalation are presented in Table 3-11.

Table 3-11. Parameter Values for Workplace Inhalation Exposures

Parameter	Units	Value	Source of Data, Comments
Air Concentration (Ca)	mg/m^3	Modeled from bath concentrations (see Table 3-9).	
Inhalation Rate (IR)	m^3/hr	1.25	U.S. EPA, 1991a (data from NIOSH, 1976).
Exposure Time (ET)			
Line Operation	hrs/day	8	Default value for occupational exposure.
Working in Process Area	hrs/day	laboratory technician . . . . 2.8 maintenance worker . . . . 1.6 supervisors . . . . 5.5 wastewater treatment operator . . 1 other employee 9	90th percentile of hours/week reported from PWB Workplace Practices Questionnaire, assuming a 5-day work week.
Exposure Frequency (EF)			
Line Operation & Working in Process Area	days/yr	HASL (NC) . . . . 44 HASL (C) . . . . 22 Nickel/Gold (NC) . . . . 212 Nickel/Palladium/Gold (NC) . 280 OSP (NC) . . . . 35 OSP (C) . . . . 16 Immersion Silver (C) . . . . . . 64 Immersion Tin (NC) . . . . 75 Immersion Tin (C) 107	From process cost model, based on the number of days per year required to produce 260,000 ssf of finished PWB. Assumed this is the time worked per year.
Exposure Duration (ED)	years	25	95[th] percentile for job tenure (Bureau of Labor Statistics, 1990). (Median tenure for U.S. males is 4 years; Bureau of Labor Statistics, 1997.)
Body Weight (BW)	kg	70	Average for adults (U.S. EPA, 1991b).
Averaging Time (AT) AT$_{CAR}$ AT$_{NC}$	days	 25,550 9,125	 70 yrs (average lifetime) x 365 d/yr 25 yrs (ED) x 365 d/yr

Workplace Dermal Exposures

Two approaches were considered for evaluating dermal exposure. The general model for potential dose rate via dermal exposure to workers from the CEB Manual (U.S. EPA, 1991a) is as follows:

$$D = SQC$$

where,

D   =   dermal potential dose rate (mg/day)
S   =   surface area of contact (cm^2)
Q   =   quantity typically remaining on skin (mg/cm^2)
C   =   concentration of chemical (percent)

Because a line operator is expected to have dermal contact with the chemicals in a given bath several times a day in the course of normal operations, the total time of contact combined with a flux rate (rate of chemical absorption through the skin) is believed to give a more realistic estimate of dermal exposure. An equation based on flux of material through the skin (from on U.S. EPA, 1992a), is as follows:

$$D = (S)(C)(f)(ET)(0.001)$$

where,

D   =   dermal potential dose rate (mg/day)
S   =   skin surface area of contact (cm^2)
C   =   chemical concentration (mg/L)
f   =   flux through skin (cm/hour)
ET   =   exposure time (hours/day)
          with a conversion factor of 0.001 L/cm^3

This second equation was used for all workplace dermal exposure estimates.[8]

As indicated earlier, daily exposures are averaged over a lifetime (70 years) for carcinogens, and over the exposure duration (e.g., 25 years working in a facility) for non-carcinogens. The following equations are used to estimate average daily doses from dermal contact:

$$LADD = (D)(EF)(ED)/[(BW)(AT_{CAR})]$$
$$ADD = (D)(EF)(ED)/[(BW)(AT_{NC})]$$

where,

D   =   dermal potential dose rate (mg/day)

General parameter values for estimating workers' potential dose rates from dermal exposure are presented in Table 3-12.

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[8] This permeability coefficient-based approach is recommended over the absorption fraction approach for compounds in an aqueous media or in air (U.S. EPA 1992a).

Table 3-12. General Parameter Values for Workplace Dermal Exposures

Parameter	Units	Value	Source of Data, Comments
Chemical Concentration (C)	%	Range of reported values and average determined from bath chemistry data.	
Skin Surface Area (S)	cm^2	800	CEB, routine immersion, 2 hands, assuming gloves not worn.
Flux Through Skin (f)	cm/hr	Default for inorganics: 0.001 estimate for organics by: $\log f = -2.72 + 0.71 \log K_{ow} - 0.0061(MW)$ (K_{ow} = octanol/water partition coefficient, MW = molecular weight)	U.S. EPA, 1992a.
Exposure Duration (ED)	years	25	95th percentile for job tenure (Bureau of Labor Statistics, 1990). (Median tenure for U.S. males is 4 years; Bureau of Labor Statistics, 1997.)
Body Weight (BW)	kg	70	U.S. EPA, 1991b.
Averaging Time (AT) AT_{CAR} AT_{NC}	days	 25,500 9,125	 70 yrs (average lifetime) x 365 d/yr 25 yrs (ED) x 365 d/yr

Dermal exposure was quantified for line operators performing routine line operation activities on non-conveyorized lines. Parameter values used in the dermal exposure equations are provided in Table 3-13.

Table 3-13. Parameter Values for Workplace Dermal Exposures for Line Operators on Non-Conveyorized Lines

Parameter/ *Activity* [a]	Units	Value		Source of Data, Comments
Exposure Time (ET)				
Line Operation [a]	hrs/day	Process / no. baths or steps	Value	Based on a default value of 8 hrs/day; corrected for typical number of baths in a process, including rinse baths, by dividing 8 hrs/day by the number of baths and/or steps in a typical process line.
		HASL (NC) / 10	0.80	
		Nickel/Gold (NC) / 14	0.57	
		Nickel/Palladium/Gold (NC) / 22	0.36	
			0.89	
		OSP (NC) / 9	0.67	
		Immersion Tin (NC) / 12		
Exposure Frequency (EF)				
Line Operation [a]	days/yr	HASL (NC) 44		From cost process simulation model, based on a throughput of 260,000 ssf.
		HASL (C) 22		
		Nickel/Gold (NC) 212		
		Nickel/Palladium/Gold (NC) 280		
		OSP (NC) 35		
		OSP (C) 16		
		Immersion Silver (C) 64		
		Immersion Tin (NC) 75		
		Immersion Tin (C) 107		

[a] Dermal exposure on non-conveyorized lines was quantified for line operation activities only, because this would result in higher line operator exposure than any other activities that may be performed (e.g., bath sampling, filter replacement).

Dermal exposure was quantified for line operators on conveyorized lines for chemical bath replacement, conveyor equipment cleaning, filter replacement, and bath sampling activities. Because conveyorized lines are enclosed and the boards are moved through the line automatically, it was assumed that dermal exposure from line operation would be negligible. Parameter values used in the exposure equations for conveyorized lines are provided in Table 3-14.

Table 3-14. Parameter Values for Workplace Dermal Exposure for Line Operators on Conveyorized Lines

Parameter/ *Activity* [a]	Units [b]	Value	Source of Data, Comments
Exposure Time (ET)			
Chemical Bath Replacement	min/occur	HASL . . . . 264 OSP . . . . 190 Immersion Silver . . . . 198 Immersion Tin 120	90th percentile from survey. Questionnaire data for replacement duration were combined regardless of process configuration
Filter Replacement	min/occur	15	90th percentile from PWB Workplace Practices Questionnaire, combined for all process types.
Chemical Bath Sampling	min/occur	HASL . . . . 15 OSP . . . . 22 Immersion Silver . . . . 1.0 Immersion Tin 5.0	90th percentile from PWB Workplace Practices Questionnaire. Questionnaire data for sampling duration were combined regardless of process configuration.
Exposure Frequency (EF)			
Chemical Bath Replacement	occur/year	HASL, cleaner . . . . 6 HASL, microetch . . . . 6 OSP, cleaner . . . . 6 OSP, microetch . . . . 6 OSP, OSP bath . . . . 1 Immersion Silver, cleaner & microetch . 6 Immersion Silver, predip . . . . 5 Immersion Silver, imm. silver bath . . . . 1 Immersion Tin, cleaner & microetch . . . 6 Immersion Tin, predip . . . . 5 Immersion Tin, imm. tin bath 1	From cost process simulation model, based on a throughput of 260,000 ssf.
Filter Replacement	occur/year	HASL . . . . 28 OSP . . . . 9 Immersion Silver . . . . 4 Immersion Tin 57	From cost process simulation model, based on a throughput of 260,000 ssf.
Chemical Bath Sampling	occur/year	HASL . . . . 67 OSP . . . . 200 Immersion Silver . . . . 253 Immersion Tin 485	From cost process simulation model, based on a throughput of 260,000 ssf.

Parameter/ *Activity* [a]	Units [b]	Value	Source of Data, Comments
Exposure Frequency and Time combined (EF x ET)			
Conveyor Equipment Cleaning	min/year	10,488	90th percentile of total duration per year from PWB Workplace Practices Questionnaire for conveyorized lines. Because a correlation between EF and ET was apparent, we did not take the 90th percentile of each term separately.

[a] Dermal exposure on conveyorized lines is quantified for specific routine activities other than line operation because on an enclosed, conveyorized line it is assumed that dermal contact from line operation would be negligible.

[b] min/occur = minutes per occurance; occur/year = number of occurances per year.

Dermal exposure was also quantified for a laboratory technician on all conveyorized and non-conveyorized lines for chemical bath sampling activities. Parameter values used in the exposure equations for a laboratory technician are provided in Table 3-15.

Table 3-15. Parameter Values for Workplace Dermal Exposure for a Laboratory Technician on Either Conveyorized or Non-Conveyorized Lines

Parameter/ *Activity*	Units [a]	Value	Source of Data, Comments
Exposure Time (ET)			
Chemical Bath Sampling	min/occur	HASL . . . . 15 Nickel/Gold . . . . 10 Nickel/Palladium/Gold . . . . 1.5 OSP . . . . 22 Immersion Silver . . . . 1.0 Immersion Tin 5.0	Questionnaire data for sampling duration were combined regardless of process configuration.
Exposure Frequency (EF)			
Chemical Bath Sampling	occur/year	HASL (NC) . . . . 135 HASL (C) . . . . 67 Nickel/Gold (NC) . . . . 954 Nickel/Palladium/Gold (NC) . . . 2,406 OSP (NC) . . . . 436 OSP (C) . . . . 200 Immersion Silver (C) . . . . 253 Immersion Tin (NC) . . . . 341 Immersion Tin (C) 485	From cost process simulation model, based on a throughput of 260,000 ssf.

[a] min/occur = minutes per occurance; occur/year = number of occurances per year.

Results

Table 3-16 presents results for estimating ADDs for inhalation and dermal workplace exposure for line operators and laboratory technicians.

Table 3-16. Estimated Average Daily Dose for Workplace Exposure From Inhalation and Dermal Contact

Chemical	ADD [a] (mg/kg-day)		
	Inhalation	Dermal	
	Line Operator	Line Operator	Laboratory Technician
HASL, Non-conveyorized			
1,4-Butenediol	1.28E-02	2.05E-03	2.82E-05
Alkylalkyne diol	NA	1.31E-05	1.81E-07
Alkylaryl sulfonate	2.43E-05	5.50E-07	7.58E-09
Alkylphenol ethoxylate	NA	1.59E-27	2.18E-29
Alkylphenolpolyethoxyethanol	NA	1.50E-26	2.06E-28
Aryl phenol	7.86E-06	1.98E-03	2.73E-05
Citric acid	NA	4.25E-03	5.85E-05
Copper Sulfate Pentahydrate	NA	4.93E-02	6.79E-04
Ethoxylated alkylphenol A	NA	1.26E-27	1.73E-29
Ethoxylated alkylphenol B	NA	8.97E-28	1.24E-29
Ethylene glycol	1.60E-02	5.17E-03	7.13E-05
Ethylene glycol monobutyl ether	1.53E-01	3.53E-02	4.86E-04
Fluoboric acid	NA	1.35E-02	1.86E-04
Gum	NA	NA [b]	NA [b]
Hydrochloric acid	1.16E-03	2.28E-02	3.15E-04
Hydrogen peroxide	6.81E-03	5.55E-02	7.66E-04
Hydroxyaryl acid	NA	9.52E-04	1.31E-05
Hydroxyaryl sulfonate	NA	3.35E-05	4.62E-07
Phosphoric acid	2.01E-03	6.69E-02	9.22E-04
Potassium peroxymonosulfate	NA	1.11E-01	1.53E-03
Sodium benzene sulfonate	NA	1.85E-07	2.55E-09
Sodium hydroxide	NA	1.86E-04	2.57E-06
Sulfuric acid	NA	2.34E-01	3.23E-03
HASL, Conveyorized			
1,4-Butenediol	NA	8.53E-05	6.35E-06
Alkylalkyne diol	NA	5.47E-07	4.07E-08
Alkylaryl sulfonate	NA	2.29E-08	1.71E-09
Alkylphenol ethoxylate	NA	6.61E-29	4.92E-30
Alkylphenolpolyethoxyethanol	NA	6.23E-28	4.64E-29

Chemical	ADD [a] (mg/kg-day)		
	Inhalation	Dermal	
	Line Operator	Line Operator	Laboratory Technician
Aryl phenol	NA	8.26E-05	6.15E-06
Citric acid	NA	1.77E-04	1.32E-05
Copper sulfate pentahydrate	NA	2.05E-03	1.53E-04
Ethoxylated alkylphenol A	NA	5.24E-29	3.90E-30
Ethoxylated alkylphenol B	NA	3.74E-29	2.78E-30
Ethylene glycol	NA	2.15E-04	1.60E-05
Ethylene glycol monobutyl ether	NA	1.47E-03	1.09E-04
Fluoboric acid	NA	5.62E-04	4.19E-05
Gum	NA	NA [b]	NA [b]
Hydrochloric acid	NA	9.51E-04	7.08E-05
Hydrogen peroxide	NA	2.31E-03	1.72E-04
Hydroxyaryl acid	NA	3.97E-05	2.95E-06
Hydroxyaryl sulfonate	NA	1.40E-06	1.04E-07
Phosphoric acid	NA	2.79E-03	2.08E-04
Potassium peroxymonosulfate	NA	4.64E-03	3.45E-04
Sodium benzene sulfonate	NA	7.72E-09	5.75E-10
Sodium hydroxide	NA	7.75E-06	5.77E-07
Sulfuric acid	NA	9.76E-03	7.27E-04
Nickel/Gold, Non-conveyorized			
Aliphatic acid A	4.86E-01	2.35E-02	1.53E-03
Aliphatic acid B	3.38E-06	1.56E-03	1.02E-04
Aliphatic acid E	6.43E-01	1.41E-02	9.16E-04
Aliphatic dicarboxylic acid A	6.59E-04	4.94E-03	3.21E-04
Aliphatic dicarboxylic acid C	3.12E-04	1.75E-03	1.13E-04
Alkylamino acid B	NA	5.38E-06	3.49E-07
Alkyldiol	1.37E-01	1.66E-02	1.08E-03
Alkylphenolpolyethoxyethanol	NA	5.18E-26	3.36E-27
Ammonia compound B	1.61E-04	2.65E-04	1.72E-05
Ammonium chloride	NA	2.08E-01	1.35E-02
Ammonium hydroxide	7.76E-03	1.34E-01	8.71E-03
Citric acid	NA	4.79E-03	3.11E-04
Copper sulfate pentahydrate	NA	1.71E-01	1.11E-02
Ethoxylated akylphenol B	NA	3.11E-27	2.02E-28
Hydrochloric acid	1.63E-01	2.08E+00	1.35E-01
Hydrogen peroxide	2.40E-02	1.36E-01	8.84E-03
Hydroxyaryl acid	NA	3.30E-03	2.14E-04

Chemical	ADD [a] (mg/kg-day)		
	Inhalation	Dermal	
	Line Operator	Line Operator	Laboratory Technician
Inorganic metallic salt A	1.97E-07	8.00E-06	5.19E-07
Inorganic metallic salt A (LADD) [c]	7.04E-08	2.85E-06	1.85E-07
Inorganic metallic salt B	1.31E-05	5.31E-04	3.45E-05
Inorganic metallic salt C	1.37E-07	5.55E-06	3.61E-07
Malic acid	1.41E-03	2.10E-03	1.37E-04
Nickel sulfate	3.49E-03	1.41E-01	9.17E-03
Palladium chloride	NA	5.01E-03	3.25E-04
Phosphoric acid	7.67E-03	1.93E-01	1.25E-02
Potassium compound	6.59E-03	2.66E-01	1.73E-02
Potassium gold cyanide	NA	1.14E-02	7.39E-04
Potassium peroxymonosulfate	NA	NA [d]	NA [d]
Sodium salt	NA	3.41E-01	2.22E-02
Sodium hydroxide	NA	6.45E-04	4.19E-05
Sodium hypophosphite	4.02E-03	1.62E-01	1.05E-02
Substituted amine hydrochloride	NA	2.27E-01	1.48E-02
Sulfuric acid	NA	8.55E-01	5.55E-02
Transition metal salt	NA	2.27E-03	1.48E-04
Urea compound B	4.80E-06	2.40E-05	1.56E-06
Nickel/Palladium/Gold, Non-conveyorized			
Aliphatic acid B	4.63E-06	1.32E-03	3.23E-05
Aliphatic acid E	1.17E+00	1.58E-02	3.88E-04
Aliphatic dicarboxylic acid A	8.98E-04	4.16E-03	1.02E-04
Aliphatic dicarboxylic acid C	4.26E-04	1.47E-03	3.61E-05
Alkylamino acid B	NA	8.01E-06	1.97E-07
Alkyldiol	1.85E-01	1.40E-02	3.43E-04
Alkylpolyol	NA	3.56-03	8.76E-05
Amino acid salt	NA	6.39E-04	1.57E-05
Amino carboxylic acid	NA	1.11E-05	2.73E-07
Ammonia compound A	NA	1.60E-01	3.92E-03
Ammonia compound B	2.20E-04	2.23E-04	5.48E-06
Ammonium hydroxide	1.71E-02	1.91E-01	4.70E-03
Citric acid	NA	4.91E-03	1.21E-04
Copper sulfate pentahydrate	NA	1.43E-01	3.53E-03
Ethoxylated alkylphenol	NA	2.61E-27	6.42E-29

Chemical	ADD [a] (mg/kg-day)		
	Inhalation	Dermal	
	Line Operator	Line Operator	Laboratory Technician
Ethylenediamine	5.32E-04	4.14E-04	1.02E-05
Hydrochloric acid	2.35E-01	3.92E-01	9.63E-03
Hydrogen peroxide	3.11E-02	1.14E-01	2.81E-03
Hydroxyaryl acid	NA	2.77E-03	6.81E-05
Inorganic metallic salt B	1.79E-05	2.07E-03	5.08E-05
Maleic acid	NA	1.36E-03	3.35E-05
Malic acid	1.92E-03	1.77E-03	4.34E-05
Nickel sulfate	7.50E-03	1.87E-01	4.59E-03
Palladium salt	NA	1.02E-02	2.51E-04
Phosphoric acid	1.01E-02	1.62E-01	3.98E-03
Potassium compound	8.98E-03	2.24E-01	5.50E-03
Potassium gold cyanide	NA	9.56E-03	2.35E-04
Propionic acid	2.13E-01	2.69E-02	6.60E-04
Sodium hydroxide	NA	5.42E-04	1.33E-05
Sodium hypophosphite	7.11E-03	1.93E-01	4.75E-03
Sodium salt	NA	4.78E-01	1.18E-02
Substituted amine hydrochloride	NA	1.91E-01	4.70E-03
Sulfuric acid	NA	4.99E-01	1.23E-02
Surfactant	NA	3.19E-04	7.83E-06
Transition metal salt	NA	1.91E-03	4.70E-05
Urea compound B	1.28E-05	3.94E-05	9.67E-07
OSP, Non-conveyorized			
Acetic acid	7.79E-02	3.75E-02	2.45E-03
Alkylaryl imidazole	NA	5.50E+00	3.59E-01
Aromatic imidizole product	NA	6.33E-03	4.13E-04
Arylphenol	6.18E-06	1.77E-03	1.16E-04
Copper ion	NA	4.95E-02	3.23E-03
Copper salt C	NA	1.36E-03	8.89E-05
Copper sulfate pentahydrate	NA	4.41E-02	2.88E-03
Ethoxylated alkylphenol	NA	8.03E-28	5.24E-29
Ethylene glycol	2.38E-02	4.63E-03	3.02E-04
Gum	NA	NA [b]	NA [b]
Hydrochloric acid	2.04E-03	2.33E-02	1.52E-03
Hydrogen peroxide	1.92E-03	1.78E-02	1.16E-03

Chemical	ADD [a] (mg/kg-day)		
	Inhalation	Dermal	
	Line Operator	Line Operator	Laboratory Technician
Hydroxyaryl acid	NA	8.52E-04	5.57E-05
Hydroxyaryl sulfonate	NA	3.00E-05	1.96E-06
Phosphoric acid	1.27E-03	4.98E-02	3.25E-03
Sodium hydroxide	NA	1.67E-04	1.09E-05
Sulfuric acid	NA	2.55E-01	1.66E-02
OSP, Conveyorized			
Acetic acid	NA	1.78E-03	5.30E-04
Alkylaryl imidazole	NA	2.61E-01	7.78E-02
Aromatic imidizole product	NA	3.00E-04	8.94E-05
Aryl phenol	NA	8.93E-05	2.51E-05
Copper ion	NA	2.34E-03	6.99E-04
Copper salt C	NA	6.45E-05	1.92E-05
Copper sulfate pentahydrate	NA	2.22E-03	6.23E-04
Ethoxylated alkylphenol	NA	4.04E-29	1.13E-29
Ethylene glycol	NA	2.33E-04	6.54E-05
Gum	NA	NA [b]	NA [b]
Hydrochloric acid	NA	1.17E-03	3.30E-04
Hydrogen peroxide	NA	8.96E-04	2.51E-04
Hydroxyaryl acid	NA	4.29E-05	1.20E-05
Hydroxyaryl sulfonate	NA	1.51E-06	4.24E-07
Phosphoric acid	NA	2.50E-03	7.03E-04
Sodium hydroxide	NA	8.38E-06	2.35E-06
Sulfuric acid	NA	1.28E-02	3.60E-03
Immersion Silver, Conveyorized			
1,4-Butenediol	NA	3.07E-04	6.48E-06
Alkylamino acid A	NA	1.71E-04	3.79E-06
Fatty amine	NA	5.75E-01	1.28E-02
Hydrogen peroxide	NA	1.85E-02	3.91E-04
Nitrogen acid	NA	3.95E-03	8.75E-05
Nonionic surfactant	NA	9.23E-03	2.04E-04
Phosphoric acid	NA	2.02E-02	4.26E-04
Silver nitrate	NA	1.51E-04	3.48E-06
Sodium hydroxide	NA	8.72E-03	1.93E-04
Sulfuric acid	NA	7.55E-04	1.59E-05

Chemical	ADD [a] (mg/kg-day)		
	Inhalation	Dermal	
	Line Operator	Line Operator	Laboratory Technician
Immersion Tin, Non-conveyorized			
Aliphatic acid D	6.14E-02	8.22E-03	9.54E-05
Alkylalkyne diol	NA	1.88E-05	2.19E-07
Alkylamino acid B	NA	1.79E-06	2.08E-08
Alkylaryl sulfonate	5.74E-05	7.88E-07	9.15E-09
Alkylimine dialkanol	NA	1.84E-05	2.13E-07
Alkylphenol ethoxylate	NA	2.27E-27	2.64E-29
Bismuth compound	NA	4.02E-05	4.66E-07
Citric acid	NA	7.65E-02	8.88E-04
Cyclic amide	4.90E-02	1.15E-02	1.34E-04
Ethoxylated alkylphenol	NA	1.80E-27	2.09E-29
Ethylene glycol monobutyl ether	3.75E-01	5.06E-02	5.87E-04
Fluoboric acid	NA	1.94E-02	2.25E-04
Hydrochloric acid	2.03E-03	1.13E-02	1.31E-04
Hydroxy carboxylic acid	8.26E-02	7.03E-03	8.16E-05
Methane sulfonic acid	NA	1.62E+00	1.88E-02
Phosphoric acid	1.66E-03	4.75E-02	5.51E-04
Potassium peroxymonosulfate	NA	1.60E-01	1.85E-03
Quantenary alkylammonium chlorides	NA	7.60E-04	8.83E-06
Silver salt	NA	6.03E-06	7.00E-08
Sodium benzene sulfonate	NA	2.66E-07	3.08E-09
Sodium phosphorus salt	NA	1.41E-01	1.64E-03
Stannous methane sulfonic acid	NA	2.18E-02	2.53E-04
Sulfuric acid	NA	4.62E-01	5.37E-03
Thiourea	NA	1.89E-02	2.20E-04
Tin chloride	NA	2.19E-02	2.55E-04
Unspecified tartrate	NA	1.77E-03	2.06E-05
Urea	NA	3.68E-03	4.27E-05
Urea compound C	5.55E-01	2.37E-02	2.75E-04
Vinyl polymer	NA	1.81E-32	2.10E-34
Immersion Tin, Conveyorized			
Aliphatic acid D	NA	1.33E-03	2.32E-04
Alkylalkyne diol	NA	3.17E-06	5.31E-07
Alkylamino acid B	NA	2.89E-07	5.05E-08
Alkylaryl sulfonate	NA	1.33E-07	2.22E-08

Chemical	ADD [a] (mg/kg-day)		
	Inhalation	Dermal	
	Line Operator	Line Operator	Laboratory Technician
Alkylimine dialkanol	NA	2.98E-06	5.17E-07
Alkylphenol ethoxylate	NA	3.83E-28	6.41E-29
Bismuth compound	NA	6.50E-06	1.13E-06
Citric acid	NA	1.24E-02	2.16E-03
Cyclic amide	NA	1.87E-03	3.25E-04
Ethoxylated alkylphenol	NA	3.04E-28	5.08E-29
Ethylene glycol monobutyl ether	NA	8.52E-03	1.43E-03
Fluoboric acid	NA	3.26E-03	5.46E-04
Hydrochloric acid	NA	1.82E-03	3.18E-04
Hydroxy carboxylic acid	NA	1.14E-03	1.98E-04
Methane sulfonic acid	NA	2.69E-01	4.56E-02
Phosphoric acid	NA	8.00E-03	1.34E-03
Potassium peroxymonosulfate	NA	2.69E-02	4.50E-03
Quantenary alkylammonium chlorides	NA	1.23E-04	2.14E-05
Silver salt	NA	9.75E-07	1.70E-07
Sodium benzene sulfonate	NA	4.48E-08	7.49E-09
Sodium phosphorus salt	NA	2.33E-02	3.98E-03
Stannous methane sulfonic acid	NA	3.52E-03	6.14E-04
Sulfuric acid	NA	7.69E-02	1.30E-02
Thiourea	NA	3.05E-03	5.33E-04
Tin chloride	NA	3.54E-03	6.19E-04
Unspecified tartrate	NA	2.86E-04	4.99E-05
Urea	NA	5.94E-04	1.04E-04
Urea compound C	NA	3.82E-03	6.88E-04
Vinyl polymer	NA	2.92E-33	5.09E-34

[a] Average Daily Dose (ADD) unless otherwise noted.

[b] Dermal absorption not expected due to large molecular size.

[c] LADD is used for calculating cancer risk, and is calculated using a carcinogen averaging time (AT_{CAR}) of 70 years.

Note: The numeric format used in these tables is a form of scientific notation, where "E" replaces the " x 10ⁿ". Scientific notation is typically used to present very large or very small numbers. For example, 1.2E-04 is the same as 1.2×10^{-4}, which is the same as 0.00012 in common decimal notation.

[d] Bath concentration not available.

NA: Not Applicable. Unless otherwise noted, a number was not calculated because the chemical's vapor pressure is below the 1×10^{-3} torr cutoff and it is not used in any sparged bath. Inhalation exposures are therefore expected to be negligible.

ND: Not determined because a required value was not available.

Occupational Exposure to Elemental Lead

Modeling Occupational Lead Exposure. We estimated occupational exposure to lead based on EPA guidelines for lead ingestion in soil (U.S. EPA, 1996a). This includes modeling worker blood-lead levels using the following equation:

$$PbB_{adult_{central}} = PbB_{adult_0} + (Pb_S)(BKSF)(IR_S)(AF_S)(EF_S) \div AT$$

where,

$PbB_{adult, central}$	=	central estimate of adult blood-lead concentrations (Fg/dl)
$PbB_{adult, 0}$	=	typical background adult blood-lead concentration (Fg/dl)
Pb_S	=	lead concentration (Fg/g)
$BKSF$	=	biokinetic slope factor (Fg/dl)
IR_s	=	intake rate (g/day)
AF_s	=	gastrointestinal absorption factor (unitless fraction)
EF_s	=	exposure frequency (days/year)
AT	=	averaging time (days/year)

Lead can be easily passed along to an unborn fetus via the placenta. Using the EPA guidelines (U.S. EPA, 1996a), we also estimated fetal blood-lead levels, assuming a pregnant worker, by:

$$PbB_{fetal, 0.95} = PbB_{adult,central} \times GSD_{i, adult} \times R_{fetal/maternal}$$

where,

$PbB_{fetal, 0.95}$	=	95 percent estimate of fetal blood-lead levels (Fg/dl)
$PbB_{adult,central}$	=	central estimate of adult blood-lead concentrations (Fg/dl)
$GSD_{i, adult}$	=	estimated value of the individual geometric standard deviation (dimensionless)
$R_{fetal/maternal}$	=	fetal/maternal lead concentration at birth (dimensionless)

These equations were developed for exposure to lead in soil and dust, and were modified for the surface finishing situation by considering lead in solder, rather than soil. Our treatment of each term in the model is discussed below.

Estimated Adult Blood-Lead Concentration ($PbB_{adult, central}$). This represents the central estimate of blood-lead in adults exposed to the HASL process, measured in Fg/dl.

Background Blood-Lead Concentration ($PbB_{adult, 0}$). This value represents the typical blood-lead concentration of adults who are not exposed to lead at the site that is being assessed, and is measured in Fg/dl. A value of 1.95 is used, based on a typical range of 1.7 - 2.2 (Fg/dl) (U.S. EPA, 1996a).

Lead Concentration in Source (Pb$_S$). This is an average estimate of the amount of lead that is present in solder, and is measured in µg/g. For PWB facilities, the lead concentration of solder was used instead of soil lead concentration. A value of 37,000 µg/g (37 percent) was used, based on typical proportion of lead in tin/lead solder.

Biokinetic Slope Factor. The biokinetic slope factor (BKSF) relates the increase of typical adult blood-lead concentrations to the average daily lead uptake. The recommended default value is 0.4 µg Pb/dl blood per µg Pb absorbed/day. This value is derived from Pocock et al. (1983) and Sherlock et al. (1984) as cited by the U.S. EPA (1996a). (Both studies involved the amount of lead in tap water, and both predict higher blood-lead concentrations than expected in today's average U.S. population.)

Intake Rate. The use of this model is based on the assumption that solder could adhere to a workers' hands from routine handling, and be subsequently ingested. Although no studies were found that address the amount of lead that might be ingested by a worker handling solder specifically for a HASL process, Monsalve (1984) investigated hand soldering and pot tinning operations. Based on surface wipe samples and samples from worker's hands, a "conservative overestimate" of 30 µg Pb per day ingested was calculated.[9] In addition to this intake rate (IRs), two values based on soil ingestion studies were used in the model: an average soil ingestion rate for adults, based on tracer studies, of 10 mg (Stanek et al., 1997) and the adult central estimate for soil ingestion of 50 mg from the EPA's *Exposure Factors Handbook* (U.S. EPA, 1997a).

Gastrointestinal Absorption Factor. The gastrointestinal absorption factor (AF$_s$) represents the absolute gastrointestinal absorption fraction for ingested lead in soil. This value was determined by multiplying the absorption factor for soluble lead by the bioavailiability of lead in soil. Three factors that were considered in determining this value are the variability of food intake, lead intake, and lead form/particle size (U.S. EPA, 1996a). The soil value of 0.12 is used due to the lack of information on the absorption of ingested metallic lead from tin-lead solder.

Exposure Frequency. This represents the exposure frequency (EF$_s$) to lead solder for a worker in a PWB manufacturing facility. This is the number of days that a worker is exposed to lead and is determined in days/year. The exposure frequency was increased from EPA's value of 219 (U.S. EPA, 1996a) to 250 days/year as a standard default value for occupational exposure.

Averaging Time. The averaging time (AT) is the total period of time that lead contact may occur. We used one year, or 365 days, as the AT.

Estimated Fetal/Maternal Blood Lead Concentration (PbB$_{fetal, 0.95}$). This represents the 95th percentile estimate of fetal/maternal blood-lead, and is measured in µg/dl. These results are also based on the intake rate, as discussed above.

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[9] Wipe samples from surfaces in the area ranged from 13 to 92 µg Pb per 100 cm^2, and samples from solderer's hands ranged from 3 to 32 µg Pb per 100 cm^2.

Individual Blood Lead Geometric Standard Deviation (GSD$_i$). The GSD$_i$ is used to measure the inter-individual variability of blood-lead concentrations in a population whose members are exposed to the same non-residential environmental lead levels. A value of 1.8 is recommend for homogeneous populations and 2.1 for heterogeneous populations. The values for GSD$_i$ are estimated in the population of concern. If this is not possible, the GSD$_i$ is estimated using a surrogate population. Factors used to estimate the GSD$_i$ are variability in exposure, biokinetics, socioeconomic/ethnic characteristics, degree of urbanization, and geographical location. Using these factors can cause a high degree of uncertainty (U.S. EPA, 1996a).

Fetal/Maternal Blood Lead Concentration Ratio (R$_{fetal/maternal}$). The R$_{fetal/maternal}$ describes the relationship between the umbilical cord and the maternal blood-lead concentration. The U.S. EPA Technical Working Group for Lead recommends a default value of 0.9 (dimensionless). This is based on two separate studies: one conducted by Goyer (1990) and the other by Graziano et al. (1990). This value was derived by comparing the fetal/maternal blood-lead concentrations at delivery. The 0.9 fetal/maternal blood-lead concentration can change due to physiological changes that include the mobilization of bone/lead stores during pregnancy, and iron and calcium deficiency due to poor nutrition (U.S. EPA, 1990; Franklin et al., 1995). The blood-lead concentration also can decrease in the later stages of pregnancy due to an increase in plasma volume, which dilutes the concentration, and an increased rate of transfer of lead to the placenta or to fetal tissue (Alexander and Delves, 1981).

Modeling Results. According to the results of the blood-lead solder model, incidental ingestion could result in blood-lead concentration for workers of 2 to 63 $\digamma$g/dL, and of 3.2 to 102 for a fetus (Table 3-17). Estimated blood-lead levels will be compared to federal health-based standards and guidlines in Section 3.4.

Table 3-17. Estimated Concentration of Lead in Adult and Fetal Blood from Incidental Ingestion of Lead in Tin/Lead Solder

Intake Rate (mg/day)	Ingestion Rate source, notes	PbB$_{adult,\ central}$ ($\digamma$g/dl)	PbB$_{fetal,\ 0.95}$ ($\digamma$g/dl)
0.03	"Conservative overestimate" based on surface wipe samples in hand-soldering operations (Monsalve, 1984).	2.0	3.2
10	Average soil ingestion rate for adults, based on tracer studies (Stanek et al., 1997).	14	23
50	Adult central estimate for soil ingestion (U.S. EPA, 1997a).	63	102

PbB$_{adult,0}$ = 1.95 $\digamma$g/dl; PbS = 37,000 $\digamma$g/g; BKSF = 0.4 $\digamma$g/dL; AF$_s$ = 0.12; EF$_s$ = 250 days/yr; AT = 365 days/yr; GSD$_{i,\ adult}$ = 1.8; and R$_{fetal/maternal}$ = 0.9

The intake rate is a major source of uncertainty in estimating exposure to workers from handling solder. A range of intake rates were used to provide a possible range of modeled blood-lead concentrations. These values provide bounding estimates only. It is expected that a smaller, but unknown, amount of solder would be ingested from a workers hands than the estimates that have been used here. Figure 3-9 shows the relationship between intake rate and blood-lead level for both an adult and fetus.
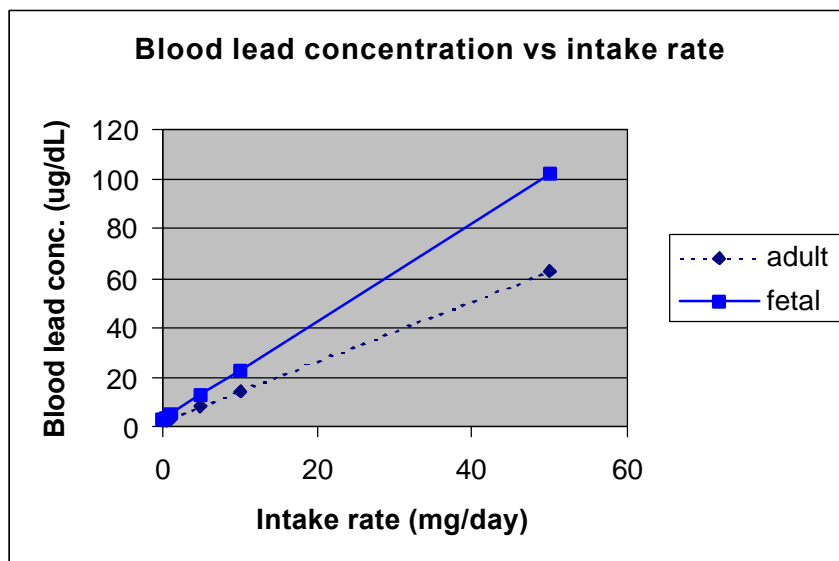
Figure 3-9. Relationship Between Intake Rate and Blood-Lead Level for Both Adult and Fetus

Monitoring Data. Lead monitoring data for HASL line operators were made available by one PWB manufacturer. For seven line operators monitored from 1986 to 1998, blood-lead levels ranged from 5 to 12 µg/dL.

Population Exposure

The equation for estimating ADDs from inhalation for a person residing near a facility is:

$$LADD = (Ca)(IR)(EF)(ED)/[(BW)(AT_{CAR})]$$
$$ADD = (Ca)(IR)(EF)(ED)/[(BW)(AT_{NC})]$$

where,

LADD	=	lifetime average daily dose (mg/kg-day) (for carcinogens)
ADD	=	average daily dose (mg/kg-day) (for non-carcinogens)
Ca	=	chemical concentration in air (mg/m³) (from air dispersion modeling, described in Section 3.2.3)
IR	=	inhalation rate (m³/day)
EF	=	exposure frequency (day/yr)
ED	=	exposure duration (years)
BW	=	average body weight (kg)
AT_{CAR}	=	averaging time for carcinogenic effects (days)
AT_{NC}	=	averaging time for non-carcinogenic chronic effects (days)

Table 3-18 presents values used for these parameters. Results for general population inhalation exposure are presented in Table 3-19.

Table 3-18. Parameter Values for Estimating Nearby Residential Inhalation Exposure

Parameter	Units	Value	Source of Data, Comments
Air Concentration (Ca)	mg/m^3		Modeled, varies by chemical and process type.
Inhalation Rate (IR)	m^3/day	15	Total home exposures for adults based on activity patterns and inhalation rates (U.S. EPA, 1997a).
Exposure Frequency (EF)	days/yr	350	Assumes 2 wks per year spent away from home (U.S. EPA, 1991b).
Exposure Duration (ED)	years	30	National upper 90th percentile at one residence (U.S. EPA, 1990).
Body Weight (BW)	kg	70	Average value for adults (U.S. EPA, 1991b).
Averaging Time (AT) AT_{CAR} AT_{NC}	days	25,550 10,950	70 yrs x 365 days/year ED x 365 days/year

Table 3-19. Estimated Average Daily Dose for General Population Inhalation Exposure

Chemical [a]	ADD (mg/kg-day) [b]
HASL, Non-conveyorized	
Ethylene glycol monobutyl ether	5.25E-05
HASL, Conveyorized	
Ethylene glycol monobutyl ether	1.04E-04
Nickel/Gold, Non-conveyorized	
Aliphatic acid A	3.45E-05
Aliphatic acid E	4.56E-05
Inorganic metallic salt A (LADD)	5.99E-12
Nickel/Palladium/Gold, Non-conveyorized	
Aliphatic acid E	6.29E-05
OSP, Non-conveyorized	
Acetic acid	3.33E-05
OSP, Conveyorized	
Acetic acid	1.26E-04
Ethylene glycol	2.04E-05
Immersion Tin, Non-conveyorized	
Urea compound C	1.11E-04
Immersion Tin, Conveyorized	
Aliphatic acid D	2.99E-05
Cyclic amide	2.39E-05
Hydroxy carboxylic acid	4.03E-05
Urea compound C	2.72E-04

[a] Only inorganic metallic salt A plus those chemicals with an emission rate of at least 23 kg/year (44 mg/min) are listed (see Table 3-9). Immersion silver had no modeled emission rates above this cut-off.

[b] Unless otherwise noted.

Note: The numeric format used in this table is a form of scientific notation, where "E" replaces the " x 10^x". Scientific notation is typically used to present very large or very small numbers. For example, 1.2E-04 is the same as 1.2 x 10^{-4}, which is the same as 0.00012 in common decimal notation.

For lead, we did not calculate an ADD. The recommended approach for evaluating lead exposure to nearby residents is to apply an EPA model, the Integrated Exposure Uptake Biokinetic (IEUBK) Model for Lead in Children (U.S. EPA, 1994), to estimate blood-lead concentrations in children based on local environmental concentrations (air, soil/dust, drinking water, food, etc). The model includes defaults based on typical concentration levels in an urban setting (U.S. EPA, 1994). The default air concentration used in the IEUBK model is 0.1 $\mu g/m^3$, which is approximately the average 1990 U.S. urban air lead concentration (U.S. EPA, 1991b). This default/background concentration is 1,000 times higher than the ambient air concentration of 0.00009 $\mu g/m^3$ estimated from a HASL process (Section 3.2.3). The model was run at various air concentrations down to 0.001 $\mu g/m^3$ (the model does not accept air concentration values less than 0.001 $\mu g/m^3$). At those levels, such small changes to the air concentration result in no real difference in estimated blood-lead concentrations compared to results obtained from using the default values (i.e., typical urban levels of lead to which a child may be exposed). These results are shown in Table 3-20. Since the estimated air concentration of lead from HASL is so far below the default/background level in air, and the model could not discern any change in children's blood-lead levels from those at average urban air concentrations, it can be concluded that general population exposure to airborne lead from the HASL process is negligible.

Table 3-20. Children's Blood-Lead Results from the IEUBK Model at Various Lead Air Concentrations

Age (year)	Blood-Lead Results (µg/dL) at Various Airborne Lead Concentrations			
	1 (µg/m³ in air)	0.1 (µg/m³ in air)	0.01 (µg/m³ in air)	0.001 (µg/m³ in air)
0.5 - 1	4.2	4.1	4.1	4.1
1-2	4.7	4.5	4.5	4.5
2-3	4.4	4.2	4.2	4.2
3-4	4.2	4.0	4.0	4.0
4-5	3.6	3.4	3.4	3.4
5-6	3.2	3.0	2.9	2.9
6-7	2.9	2.7	2.7	2.7

Note: Model default values were used for concentrations in soil/dust, drinking water, and diet.

3.2.5   Uncertainty and Variability

Because of both the uncertainty inherent in the parameters and assumptions used in estimating exposure, and the variability that is possible within a population, there is no one number that can be used to describe exposure. In addition to data and modeling limitations, discussed in Sections 3.2.3, sources of uncertainty in assessing exposure include the following:

C   Accuracy of the description of exposure setting: how well the model facility used in the assessment characterizes an actual facility; the likelihood of exposure pathways actually occurring (scenario uncertainty).
C   Missing data and limitations of workplace practices data: this includes possible effects of any chemicals that may not have been included (e.g., minor ingredients in the

formulations; possible effects of side reactions in the baths which were not considered; and questionnaire data with limited facility responses).

C   Estimating exposure levels from averaged data and modeling in the absence of measured, site-specific data.

C   Data limitations in the Source Release Assessment: releases to land could not be characterized quantitatively, as discussed in Section 3.1.

C   Chemical fate and transport model applicability and assumptions: how well the models and assumptions represent the situation being assessed, and the extent to which the models have been validated or verified (model uncertainty).

C   Parameter value uncertainty, including measurement error, sampling error, parameter variability, and professional judgement.

C   Uncertainty in combining pathways for an exposed individual.

A method typically used to provide information about the position an exposure estimate has in the distribution of possible outcomes is the use of exposure (or risk) descriptors. EPA's *Guidelines for Exposure Assessment* (U.S. EPA, 1992b) provides guidance on the use of risk descriptors, which include the following:

C   *High-end*: approximately the 90th percentile of the actual (measured or estimated) distribution. This is a plausible estimate of individual risk for those persons at the upper end of the exposure distribution, and is not higher than the individual in the population who has the highest exposure.

C   *Central tendency*: either an average estimate (based on average values for the exposure parameters) or a median estimate (based on 50th percentile or geometric mean values).

C   *What-if:* represents an exposure estimate based on postulated questions (e.g., what if the air ventilation rates were ...), in this case, making assumptions based on limited data so that the distribution is unknown. If any part of the exposure assessment qualifies as a "what-if" descriptor, then the entire exposure assessment is considered "what-if."

This exposure assessment uses whenever possible a combination of central tendency (either an average or median estimate) and high-end (90th percentile)[10] assumptions, as would be used for an overall high-end exposure estimate. The 90th percentile is used for:

C   hours per day of workplace exposure;

C   exposure frequency (days per year);

C   exposure duration in years (90th percentile for occupational and 95th percentile for residential exposures);

C   time required for chemical bath replacement; and

C   the time and frequency of filter replacements, conveyor equipment cleaning and chemical bath sampling (minutes per occurrence and number of occurrences per year).

Average values are used for:

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[10] For exposure data from the PWB Workplace Practices Questionnaire, this means that 90 percent of the facilities reported a lower value, and ten percent reported a higher value.

C   body weight;
C   concentration of chemical in bath;
C   frequency of chemical bath replacements;
C   the number of baths in a given process; and
C   bath size.

However, because some data, especially pertaining to bath concentrations and inhalation exposure are limited, and this exposure assessment does not apply to a specific facility, the entire exposure assessment should be considered "what-if."

3.2.6   Summary

This exposure assessment uses a "model facility" approach, with the goal of comparing the exposures and health risks of one surface finishing technology to the exposures and risks associated with switching to another technology. As much as possible, reasonable and consistent assumptions are used across alternatives. Data to characterize the model facility and exposure patterns for each surface finishing technology were aggregated from a number of sources, including PWB shops in the U.S., supplier data, and input from PWB manufacturers at project meetings. Thus, the model facility is not entirely representative of any one facility, and actual exposure (and risk) could vary substantially, depending on site-specific operating conditions and other factors.

Chemical exposures to PWB workers and the general population from day-to-day surface finishing line operations were estimated by combining information gathered from industry (PWB Workplace Practices Questionnaire, MSDSs, and other available information) with standard EPA exposure assumptions for inhalation rate, surface area of dermal contact, and other parameters. The pathways identified for potential exposure from surface finishing process baths were inhalation and dermal contact for workers, and inhalation contact only for the general populace living near a PWB facility.

The possible impacts of short-term exposures to high levels of hazardous chemicals addressed have not been addressed, such as those that could occur from chemical fires, spills, or other episodic releases.

Inhalation exposure could occur by breathing air containing vapor or aerosol-phase chemicals from the surface finishing process line. Inhalation exposures to workers are estimated only for non-conveyorized lines; inhalation exposure to workers from conveyorized surface finishing lines was assumed to be much lower because the lines are typically enclosed and vented to the outside.[11]

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[11] Inhalation exposures for conveyorized process configurations were initially assumed to be negligible, and are not presented separately here. Some inhalation exposure is possible, however, during sampling and bath replacement, when the baths are opened for a short period of time. After characterizing risks from inhalation for non-conveyorized lines, inhalation exposures and risks were estimated for conveyorized lines. No chemical exposures from inhalation resulted in risks above concern levels for conveyorized lines.

The daily intake for inhalation exposure to workers was calculated by first modeling chemical emissions from surface finishing baths with three air-transport mechanisms: liquid surface diffusion (desorption), bubble desorption, and aerosol generation and ejection. These chemical emission rates were combined with information from the PWB Workplace Practices Questionnaire regarding process room size and air turnover rate to estimate an average indoor air concentration for each chemical for the process area. General room ventilation was assumed, although the majority of shops have local ventilation on chemical tanks. An uncertainty and sensitivity analysis of the air transport models (U.S. EPA, 1998b) suggests that the air turnover (ventilation) rate assumption greatly influences the estimated air concentration in the process area because of its large variability.

Inhalation exposure to the human population surrounding PWB plants was estimated using the Industrial Source Complex - Long Term (ISCLT) air dispersion model. The modeled air concentrations of each contaminant were determined at 100 meters radially from a PWB facility, and the highest estimated air concentration was used. This model estimates air concentration from the process bath emission rates. These emissions were assumed to be vented to the ambient environment at the rate emitted from the baths, for all process alternatives. Inhalation exposures estimated for the public living 100 meters away from a PWB facility were very low (approximately 10,000 times lower than occupational exposures).

Dermal exposure could occur when a worker's skin comes in contact with the bath solution while dipping boards, adding replacement chemicals, etc. Although the data suggest that surface finishing line operators often do wear gloves, it was assumed in this evaluation that workers do not wear gloves to account for the fraction that do not. Otherwise, dermal exposure is expected to be negligible. For dermal exposure, the duration of contact for workers was obtained from the PWB Workplace Practices Questionnaire information. A permeability coefficient (rate of penetration through skin) was estimated for organics, and a default rate assumption was used for inorganics. Another source of uncertainty in dermal modeling lies with the assumed duration of contact. For non-conveyorized processes, the worker is assumed to have potential dermal contact for the entire time spent in the surface finishing area, divided equally among the baths. [This does not mean that a worker has both hands immersed in a bath for that entire time; but that the skin is in contact with bath solution (i.e., the hands may remain wet from contact).] This assumption may result in an overestimate of dermal exposure.

Assumptions and parameter values used in these equations are presented throughout this section. Exposure estimates are based on a combination of high end (90th percentile)[12] and average values, as would be used for a high-end exposure estimate. The 90th percentile was used for hours per day of workplace exposure, exposure frequency (days per year), exposure duration in years (90th percentile for occupational and 95th percentile for residential exposures), and the time and frequency of chemical bath and filter replacements, conveyor equipment cleaning and chemical bath sampling (minutes per occurrence and number of occurrences per year) and estimated workplace air concentrations. The average value was used for body weight,

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[12] For exposure data from the PWB Workplace Practices Questionnaire, this means that 90 percent of the facilities reported a lower value, and ten percent reported a higher value.

concentration of chemical in bath, and the number of baths in a given process. However, because some data, especially pertaining to bath concentrations and inhalation exposure, are limited and this exposure assessment does not apply to a specific facility, the entire exposure assessment should be considered "what-if."

As a "what if" exposure assessment, this evaluation is useful for comparing alternative surface finishing processes to the baseline (non-conveyorized HASL) on a consistent basis. It is also useful for risk screening, especially if actual facility conditions meet those that were assumed (i.e., given similar production rates, what chemicals may be of concern if workers do not wear gloves; what chemicals may be of concern if ventilation rates are similar to those assumed?). Finally, this assessment points to the importance of preventing dermal contact by using gloves, and of proper ventilation.

Surface water concentrations were estimated for bath constituents, with a focus on those constituents that are not typically targeted for pre-treatment by PWB facilities. This was done for conveyorized lines by estimating the amount of chemical going to wastewater from routine bath replacement, and for non-conveyorized lines by estimating the amount of chemical going to wastewater from bath replacement plus an estimated amount due to drag-out from the baths to rinse water. These amounts were then included in a stream dilution model, and if estimated surface water concentrations exceeded CCs for aquatic life, the model was refined using estimated POTW treatment efficiencies.

These exposure results, taken by themselves, are not very meaningful for evaluating surface finishing alternatives; it is the combination of hazard (Section 3.3) and exposure that defines risk. Quantitative exposure estimates are combined with available hazard data in the risk characterization (Section 3.4) for risk screening and comparison of the surface finishing process configurations.

3.3   HUMAN HEALTH AND ECOLOGICAL HAZARDS SUMMARY

This section presents a summary of the human health and ecological hazards data that are used in the risk characterization. This information is summarized from toxicity profiles prepared for chemicals identified as constituents in the baths for the surface finishing technologies evaluated. Table 2-1 lists these chemicals and identifies the surface finishing process or processes in which these chemicals are used. HASL is the predominant method now used for surface finishing. Section 2.1.4 includes more detailed information on bath constituents and concentrations. Throughout this section, proprietary chemicals are identified only by generic name, with limited information presented, in order to protect proprietary chemical identities.

3.3.1   Carcinogenicity

The potential for a chemical to cause cancer is evaluated by weight-of-evidence (WOE) classifications and by cancer potency factors, typically determined from laboratory or epidemiological studies. There are a large number of chemicals in commerce, however, (approximately 15,000 non-polymeric chemicals produced in amounts greater than 10,000 lb/year), and many of these chemicals have not yet been tested or assigned carcinogenicity classifications. The WOE classifications referenced in this risk assessment are defined below.

In assessing the carcinogenic potential of a chemical, EPA classifies the chemical into one of the following groups, according to the WOE from epidemiologic, animal and other supporting data, such as genotoxicity test results:

C   Group A: Human Carcinogen (sufficient evidence of carcinogenicity in humans).
C   Group B: Probable Human Carcinogen (B1 - limited evidence of carcinogenicity in humans; B2 - sufficient evidence of carcinogenicity in animals with inadequate or lack of evidence in humans).
C   Group C: Possible Human Carcinogen (limited evidence of carcinogenicity in animals and inadequate or lack of human data).
C   Group D: Not Classifiable as to Human Carcinogenicity (inadequate or no evidence).C Group E: Evidence of Non-Carcinogenicity for Humans (no evidence of carcinogenicity in adequate studies).

EPA has proposed a revision of its guidelines that would eliminate the above discrete categories while providing a more descriptive classification.[13]

The International Agency for Research on Cancer (IARC) uses a similar WOE method for evaluating potential human carcinogenicity based on human data, animal data, and other supporting data. A summary of the IARC carcinogenicity classification system includes:

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[13] The "Proposed Guidelines for Carcinogen Risk Assessment" (U.S. EPA, 1996b) proposes the use of WOE descriptors, such as "Likely" or "Known," "Cannot be determined," and "Not likely," in combination with a hazard narrative, to characterize a chemical's human carcinogenic potential, rather than the classification system described above.

C   Group 1:   Carcinogenic to humans.
C   Group 2A: Probably carcinogenic to humans.
C   Group 2B: Possibly carcinogenic to humans.
C   Group 3:   Not classifiable as to human carcinogenicity.
C   Group 4:   Probably not carcinogenic to humans.

Both of these classification schemes represent judgements regarding the likelihood of human carcinogenicity. Table 3-21 lists all surface finishing chemicals that have been classified by EPA or IARC. The National Toxicology Program (NTP) is an additional source used to classify chemicals, but its classifications are based only on animal data from NTP studies.

Table 3-21. Available Carcinogenicity Information

Chemical Name [a]	Cancer Slope Factor (Inhalation Unit Risk) $(\mu g/m^3)^{-1}$	Cancer Slope Factor (Oral) $(mg/kg\text{-}day)^{-1}$	Comments/Classification
Known, probable, or possible human carcinogens			
Inorganic metallic salt A	Not reported [b]	ND	Human carcinogen or probable human carcinogen. [c]
Sulfuric acid [d]	ND	ND	IARC Group 1 [e] (IARC 1992).
Lead	ND	ND	EPA Class B2 [f] (IRIS, 1999); IARC Group 2B [g] (IARC, 1987).
Thiourea	ND	ND	IARC Group 2B [g] (IARC 1974).
Urea compound B	ND	ND	Possible human carcinogen. [c]
Other weight-of-evidence (WOE) or other information available			
Nickel sulfate	ND	ND	Nickel refinery dust is IARC Group 1 [e] (IARC, 1990). No assessment available for soluble salts of nickel.
Copper ion, Copper salt, and Copper sulfate pentahydrate	ND	ND	Copper is EPA Class D [h] (IRIS, 1998).
Hydrochloric acid	ND	ND	IARC Group 3 [i] (HSDB, 1998), excess lung and laryngeal cancer occurred in workers exposed to HCL mist; however, many of these cases involved exposure to acid mixtures (Perry et al., 1994).
Hydrogen peroxide	ND	ND	IARC Group 3 [i] (IARC, 1987), stomach tumors occurred in mice (Ito et al., 1981).
Vinyl polymer	ND	ND	Not classifiable according to EPA and/or IARC. [c]
Silver nitrate	ND	ND	Silver is EPA Class D [h] (IRIS, 1998).

Chemical Name [a]	Cancer Slope Factor (Inhalation Unit Risk) $(\mu g/m^3)^{-1}$	Cancer Slope Factor (Oral) $(mg/kg\text{-}day)^{-1}$	Comments/Classification
Silver salt	ND	ND	Not classifiable according to EPA and/or IARC. [c]
Stannous methane sulfonic acid	ND	ND	EPA Class D [h] (U.S. EPA, 1987a).
Tin chloride	ND	ND	EPA Class D [h] or IARC Group 3[i] (U.S. EPA, 1987a).
Palladium chloride	ND	ND	No classification; mice administered palladium in drinking water had a significantly higher incidence of malignant tumors (Schroeder and Mitchener, 1971).
Propionic acid	ND	ND	No classification; tumors in forestomach of rats (Clayson et al., 1991).

[a] Only those chemicals with available data or classifications are listed.
[b] The unit risk value is not reported here to protect confidential ingredient identity.
[c] Specific EPA and/or IARC groups not reported in order to protect proprietary chemical identities.
[d] Classification pertains to the strong inorganic acid mist.
[e] IARC Group 1: Human Carcinogen.
[f] EPA Class B2: Probable Human Carcinogen (sufficient evidence of carcinogenicity in animals with inadequate or lack of evidence in humans).
[g] IARC Group 2B: Possibly carcinogenic to humans.
[h] EPA Class D: Not classifiable as to human carcinogenicity.
[i] IARC Group 3: Not classifiable as to its carcinogenicity to humans.
ND: No Data, a cancer slope factor has not been determined for this chemical.

For carcinogenic effects, there is presumably no level of exposure that does not pose a small, but finite, probability of causing a response. This type of mechanism is referred to as "non-threshold." When the available data are sufficient for quantification, EPA develops an estimate of the chemical's carcinogenic potency expressed as a "slope factor." The slope factor (q_1^*) is a measure of an individual's excess risk or increased likelihood of developing cancer if exposed to a chemical (expressed in units of $[mg/kg\text{-}day]^{-1}$). More specifically, q_1^* is an approximation of the upper bound of the slope of the dose-response curve using the linearized, multistage procedure at low doses. "Unit risk" is an equivalent measure of potency for air or drinking water concentrations and is expressed as the upper bound excess lifetime cancer risk per Fg/m^3 in air, or as risk per Fg/L in water, for continuous lifetime exposures. (Unit risk is simply a transformation of slope factor into the appropriate scale.) Slope factors and unit risks can be viewed as quantitatively derived judgements of the magnitude of carcinogenic effect. These estimates will continue to be used whether the current EPA WOE guidelines are retained or the new proposals are adopted. Their derivation, however, may change for future evaluations.

EPA risk characterization methods require a slope factor or unit risk to quantify the upper bound, excess cancer risk from exposure to a known or suspected carcinogen. There is only one chemical, inorganic metallic salt A, with a slope factor. Therefore, this is the only chemical for which cancer risk can be characterized (see Section 3.4, Risk Characterization).

3.3.2   Chronic Effects (Other than Carcinogenicity)

Adverse effects, other than cancer and gene mutations, are generally assumed to have a dose or exposure threshold. Therefore, a different approach is used to evaluate toxic potency and risk for these "systemic effects." Systemic toxicity means an adverse effect on any organ system following absorption and distribution of a toxicant to a site in the body distant from the toxicant's entry point. A reference dose (RfD) is an estimate (with uncertainty spanning perhaps an order of magnitude) of the daily exposure through ingestion to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious non-cancer effects during a lifetime (in mg/kg-day). Similarly, a reference concentration (RfC) is an estimate (with uncertainty spanning perhaps an order of magnitude) of the daily inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious non-cancer effects during a lifetime (in mg/m^3) (Barnes and Dourson, 1988). RfDs and RfCs also can be derived from developmental toxicity studies. However, this was not the case for any of the surface finishing chemicals evaluated. RfDs and RfCs are derived from EPA peer-reviewed study results (for values appearing in EPA's Integrated Risk Information System [IRIS]), together with uncertainty factors regarding their applicability to human populations. Table 3-22 presents a summary of the available RfC and RfD information obtained from IRIS and EPA's Health Effects Assessment Summary Tables (HEAST) for non-proprietary chemicals. An additional proprietary chemical has an RfC and an RfD; these data are not reported in order to protect the identity of the confidential ingredient.

Table 3-22. Summary of RfC and RfD Information Used in Risk Characterization for Non-Proprietary Ingredients

Chemical Name [a]	Inhalation RfC [b] (mg/m³)	Comments [c] (Inhalation)	Oral/Dermal RfD [b] (mg/kg/day)	Comments [c] (Oral/Dermal)
Ammonium chloride, Ammonium hydroxide	0.1 [d] (IRIS)	Ammonia: decreased lung function (IRIS, 1999).	0.2 [e] (IRIS)	Ammonium sulfamate: rats, drinking water, 90 days, decreased body weight (Gupta et al., 1979; IRIS, 2000).
Ethylenediamine	ND		0.02 (HEAST)	Rats, 3 months, increased heart weight and hematologic changes (U.S. EPA, 1997b).
Ethylene glycol	ND		2 (IRIS)	Rats, kidney toxicity (IRIS, 1999).
Ethylene glycol monobutyl ether	13 (IRIS)	Changes in red blood cell count (IRIS, 1999).	0.5 (IRIS)	Changes in mean corpuscular volume (IRIS, 1999).
Hydrochloric acid	0.02 (IRIS)	Rats, hyperplasia of nasal mucosa, larynx, and trachea (IRIS, 1998).	ND	
Lead [f]	ND: Some health effects of lead, particularly changes in the levels of certain blood enzymes and in aspects of children's neurobehavioral development, may occur at blood- lead levels so low as to be essentially without a threshold. EPA considers it inappropriate to develop an RfD for inorganic lead (IRIS, 2000).			
Nickel sulfate	0.00053 [g] (MRL)	Rats, lung inflammation (ATSDR, 1997a).	0.02 (IRIS) (soluble salts of nickel)	Rats, decreased body and organ weight (IRIS, 1998).
Phosphoric acid	0.01 (IRIS)	Rats, histologic lesions in tracheobronchiolar region (IRIS, 1998).	221 (ADI)	(U.S. EPA, 1997c; WHO, 1974).
Potassium gold cyanide	ND		0.02 [h] (IRIS)	Cyanide: rats, 2 year, weight loss, thyroid effects and myelin degeneration, (IRIS, 1998).
Silver nitrate	ND		0.005 [i] (IRIS)	Silver-argyria (benign but permanent bluish-gray discoloration of skin) (Gaul and Staud, 1935).

Chemical Name [a]	Inhalation RfC [b] (mg/m³)	Comments [c] (Inhalation)	Oral/Dermal RfD [b] (mg/kg/day)	Comments [c] (Oral/Dermal)
Stannous methane sulfonic acid, Tin, and Tin chloride	ND		0.6 [j] (HEAST)	Tin and inorganic compounds: rats, 2 year, histopathologic study (U.S. EPA, 1997b).
Sulfuric acid	0.07 (HEAST)	Acceptable air concentration for humans based on respiratory effects (U.S. EPA, 1997b).	ND [k]	

[a] Only non-proprietary chemicals with available data are listed.

[b] The type of value is noted in parentheses:

> IRIS: EPA-derived and peer-reviewed values listed in the Integrated Risk Information System. IRIS values are preferred and used whenever available.

> HEAST: EPA-derived RfD or RfC listed in the Health Effects Assessment Summary Tables. These values have not undergone the same level of review as IRIS values.

> ADI: Acceptable daily intake, developed by the World Health Organization (WHO).

> MRL: Minimal risk level, developed by the Agency for Toxic Substances and Disease Registry (ATSDR) in a manner similar to EPA-derived values.

[c] Comments may include exposure route, test animal, duration of test, effects, and source of data.

[d] In the risk calculations, conversion factors are used based on the molecular weights of ammonia, ammonium chloride, and ammonium hydroxide.

[e] In the risk calculations, conversion factors are used based on the molecular weights of ammonium sulfamate, ammonium chloride, and ammonium hydroxide.

[f] More information on lead is presented in Section 3.4.6 of the Risk Characterization.

[g] Value given represents a chronic inhalation minimum risk level (MRL). Although the test substance was nickel sulfate hexahydrate, the reported value is 0.0002 mg/m³ *as nickel.* This was converted in the risk calculations based on the molecular weights of nickel and nickel sulfate.

[h] A conversion factor is used in the risk calculations based on molecular weights of cyanide and potassium gold cyanide. This RfD is only relevant to the oral route; potassium gold cyanide is expected to be chemically stable except under highly acidic conditions such as those found in the stomach (pH 1-2).

[i] A conversion factor is used in the risk calculations based on molecular weights of silver and silver nitrate.

[j] Conversion factors are used in the risk calculations based on molecular weights of tin, tin chloride, and stannous methane sulfonic acid.

[k] Although chronic toxicity values have not been established, repeated skin contact with low concentrations of sulfuric acid causes skin dessication, ulceration of the hands, and chronic inflammation around the nails.

ND: No data, RfC or RfD not available.

When an RfD or RfC was not available for a chemical, other toxicity values were used, preferably in the form of a "no-observed-adverse-effect level" (NOAEL) or "lowest-observed-adverse-effect level" (LOAEL). These toxicity values were obtained from the published scientific literature, as well as unpublished data submitted to EPA on chemical toxicity in chronic or subchronic studies. Typically, the lowest NOAEL or LOAEL value from a well-conducted study was used. (If study details were not presented or the study did not appear to be valid, the reported NOAEL/LOAELs were not used.) But, unlike the majority of RfD/RfCs, NOAEL/LOAELs have not received EPA peer-review of the studies on which the values are based, and uncertainty factors have not been considered.

The LOAEL is the lowest dose level in a toxicity test at which there are statistically or biologically significant increases in frequency or severity of adverse effects in the exposed population over its appropriate control group (in mg/kg-day, or mg/m^3 for inhalation). The NOAEL is the highest dose level in a toxicity test at which there is no statistically or biologically significant increase in the frequency or severity of adverse effects in the exposed population over its appropriate control (in mg/kg-day, or mg/m^3 for inhalation). LOAEL values are presented only where NOAELs were not available. Table 3-23 presents a summary of the available NOAEL and LOAEL values for non-proprietary chemicals. Chemicals having potential developmental toxicity were identified based on the data provided in the toxicity profiles. These data are summarized in Table 3-24. An additional 5 proprietary chemicals have inhalation NOAELs or LOAELs, and 13 have oral NOAELs or LOAELs; these data are not reported in order to protect the identity of confidential ingredients.

Neither RfDs/RfCs nor LOAELs/NOAELs were available for some chemicals in each surface finishing process alternative. For these chemicals, no quantitative estimate of risk could be calculated. EPA's Structure-Activity Team (SAT)[14] has reviewed the chemicals without relevant toxicity data to determine if these chemicals are expected to present a toxicity hazard. This review was based on available toxicity data on structural analogues of the chemicals, expert judgement, and known toxicity of certain chemical classes and/or moieties. Chemicals received a concern level rank of high, moderate-high, moderate, moderate-low, or low. Results of the SAT evaluation are presented in Table 3-25. A summary of toxicity data available for the chemicals is presented in Table 3-26.

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[14] The SAT is a group of expert scientists at EPA who evaluate the potential health and environmental hazards of new and existing chemicals.

Table 3-23. NOAEL/LOAEL Values Used in Risk Characterization for Non-Proprietary Ingredients

Chemical Name [a]	Inhalation NOAEL/ LOAEL [b] (mg/m³)	Comments [c] (Inhalation)	Oral/Dermal NOAEL/ LOAEL [b] (mg/kg-day)	Comments [c] (Oral/Dermal)
Acetic acid	ND [d]		195 (N)	Rats, drinking water, 2-4 months, no deaths (Sollmann, 1921).
Copper ion, Copper sulfate pentahydrate	0.6 (L) [e]	Cupric chloride: rabbits, 6 hrs/day, 5 days/wk for 4-6 wks, increase in lung tumors (U.S. Air Force, 1990).	0.056 (L) [f]	Copper: humans, 1.5 years, abdominal pain and vomiting (ATSDR, 1990a).
Ethylenediamine	145 (N) [g]	Rats, 7 hrs/day, 5 days/wk for 30 days, depilation (Pozzani and Carpenter, 1954).	NA	RfD is available (Table 3-22).
Ethylene glycol	31 (L)	Humans, 20-22 hrs/day for 30 days, respiratory irritation, headache, and backache (ATSDR, 1997b).	NA	RfD is available (Table 3-22).
Hydrogen peroxide	79 (L) [h]	Mouse, 6 weeks, 7/9 died (U.S. EPA, 1988a).	290 (L)	Mice, 35 weeks, liver, kidney, and GI effects (IARC, 1985).
Lead [i]	10 µg/dL in blood	Children, level concern in blood (CDC, 1991).	10 µg/dL in blood	Children, level concern in blood (CDC, 1991).
Propionic acid	23 (TClo) [j]	Rats, subchronic exposure (RTECS, 1998).	150 (N)	Rats, diet, lesions in GI tract (BASF, 1987; Mori, 1953; Harrison et al., 1991; Rodrigues et al., 1986).

[a] Only non-proprietary chemicals with available data are listed.

[b] (N) = NOAEL; (L) = LOAEL. When more than one NOAEL and/or LOAEL was available, only the lowest available NOAEL or LOAEL was used and is listed here. If both NOAEL and LOAEL data are available, the NOAEL is used and is listed here. If a chronic NOAEL or LOAEL was not available, other values (e.g., from shorter-term studies) were used as noted.

[c] Comments may include exposure route, test animal, duration of test, effects, and source of data.

[d] Although health effects have been noted in workers and laboratory tests from inhalation exposure to acetic acid, no appropriate chronic inhalation toxicity value is available.

[e] Conversion factors are used in the risk calculations based on molecular weights of cupric chloride, copper ion, and copper sulfate pentahydrate.

[f] A conversion factor is used in the risk calculations based on molecular weights of copper and copper sulfate pentahydrate.

[g] Not considered a "chronic" value because the study duration was less than 90 days. The value was used, however, as the best available value, rather than leaving a data gap for a chemical where adverse health effects have been noted.

[h] In the absence of other data, this value will be used as a LOAEL.

[i] More information on lead is presented in Section 3.4.5 of the Risk Characterization.

[j] TClo = The lowest dose of a chemical that is expected to cause a defined toxic effect. In the absence of other data, this is used as a LOAEL.

ND: No Data. A NOAEL or LOAEL was not available for this chemical.

NA: Not applicable. A NOAEL or LOAEL is not required because an RfC or RfD is available for this chemical.

Table 3-24. Developmental Toxicity Values Used in Risk Characterization for Non-Proprietary Ingredients

Chemical [a]	Developmental Inhalation NOAEL / LOAEL (mg/m³) [b]	Comments [c] (Inhalation)	Developmental Oral/Dermal NOAEL / LOAEL [b] (mg/kg-day)	Comments [c] (Oral/Dermal)
Ammonium chloride	ND		1,691 (N)	Mice, drinking water, after gd [d] 7, no congenital effects (Shepard, 1986).
Copper ion, Copper sulfate pentahydrate	ND		3 (L) [e]	Copper: mink, diet, increased mortality (Aulerich et al., 1982; ATSDR, 1990a).
Ethylenediamine	ND		470 (L)	Rats, gd 6-15 diet, resorption, impaired growth, missing or shortened innominate arteries, and delayed ossification of cervical vertebrae or phalanges (DePass et al., 1987).
Ethylene glycol	150 (N)	Rats and mice, 6 hr/day, gd 6-15, fetal malformations in mice (exencephaly, cleft palate, and abnormal rib and facial bones) (Shell Oil, 1992; Union Carbide, 1991).	500 (N)	Rats, gd 6-15, gavage, teratogenic effects at higher dose levels. NOAEL based on developmental effects (Bushy Run, 1995).
Ethylene glycol monobutyl ether	ND		100 (N)	Rats, gd 9-11, oral gavage, developmental toxicity (Sleet et al., 1989).

[a] Only those chemicals with available data are listed.

[b] (N) = NOAEL; (L) = LOAEL. When more than one NOAEL and/or LOAEL was available, only the lowest available NOAEL or LOAEL was used and is listed here. If both NOAEL and LOAEL data are available, the NOAEL is used and is listed here.

[c] Comments may include test effects, test animal, duration during time of gestation, exposure route, and source of data.

[d] gd = gestation day.

[e] Conversion factors are in the risk calculations based on molecular weights of copper ion and copper sulfate pentahydrate.

ND: No data available.

Table 3-25. Summary of Health Effects Information
(from Structure-Activity Team Reports)

Chemical	SAT Health Effects Pertaining to Dermal or Inhalation Exposure	Overall Concern Level
1,4-Butenediol	Expect good absorption via all routes of exposure. The primary alcohols will oxidize to the corresponding acids (fumaric or maleic) via aldehydes. There is concern for mutagenicity as an unsaturated aldehyde. This compound is expected to be irritating to the lungs and other mucous membranes. Effects on the liver and kidney and neurotoxicity (sedation) are also expected.	Low moderate
Aliphatic acid B	Expect no absorption by skin, but expect absorption by lungs and GI tract. Related compound is reported to be positive in a dominant lethal assay. Uncertain concerns for developmental toxicity and kidney toxicity. Some concern for irritation.	Moderate
Aliphatic dicarboxylic acid A	Absorption is expected to be poor through the skin and good through the lungs and GI tract. As a free acid, this compound is expected to be irritating to all exposed tissues. A mixture of acids containing this compound was tested in rats. The mixture was negative for mutagenicity but caused signs of neurotoxicity. A mixture containing the dimethyl ester of this compound was tested in acute inhalation and dermal studies because blurring of vision had been reported in humans. An increase in the anterior chamber depth in the eye was seen following inhalation and dermal exposure. This could be an indication of changes in circulation in the eye which could lead to glaucoma. A mixture of the same compounds was tested in a 1-generation reproduction study in rats via inhalation, showing a decrease in postnatal pup weight and irritation of the respiratory tract in parental animals.	Low moderate
Alkylalkyne diol	Expect poor absorption via all routes of exposure. This compound may be irritating to the eyes, lungs, and mucous membranes and cause defatting of the skin which can lead to skin irritation. There is uncertain concern for neurotoxicity and liver and kidney effects.	Low
Alkylamino acid A	Absorption is expected to be poor through the skin and good through the lungs and GI tract. This compound is expected to chelate metals such as calcium, magnesium, and zinc. Based on its potential to chelate calcium, there is concern for developmental toxicity, inhibition of blood clotting, and effects on the nervous system and muscles including effects on the heart. Chelation of zinc may cause immunotoxicity (retardation of wound healing). This compound is expected to be irritating to all exposed tissues and may be a dermal sensitizer. A salt of this compound caused developmental effects in rats. There is concern for oncogenicity and kidney toxicity. There is also a potential for male reproductive effects. This compound may be mutagenic.	Low moderate

Chemical	SAT Health Effects Pertaining to Dermal or Inhalation Exposure	Overall Concern Level
Alkylaryl imidazole	Expect good absorption via the lungs and GI tract. Absorption of the neat material is expected to be nil through the skin; however, absorption is expected to be moderate through the skin when in solution. There is concern for developmental toxicity and neurotoxicity.	Low moderate
Alkylaryl sulfonate	Absorption is expected to be nil through the skin and poor through the lungs and GI tract. There is uncertain concern for irritation to mucous membranes.	Low
Alkylimine dialkanol	Absorption is expected to be poor through the skin, moderate through the GI tract, and good through the lungs. This compound is a moderate to severe skin irritation and a severe eye irritant. It has low acute toxicity. Another analog was tested in a subchronic gavage study in rats and dogs. Cataracts were noted in rats, stomach and lung lesions consistent with irritation were seen, and liver effects were seen in female dogs. There is concern for developmental toxicity. There is little concern for mutagenicity by analogy to a similar compound.	Moderate
Amino acid salt	Absorption is expected to be nil through the skin and good through the lungs and GI tract. There is uncertain concern for developmental toxicity. This compound is an amino acid analog and may be an antimetabolite. This chemical is also expected to be an irritant to moist tissues such as the lungs and respiratory tract.	Low moderate
Ammonia compound B	Absorption is expected to be nil through the skin and good through the lungs and GI tract. This material will be irritating and/or corrosive to all exposed tissues. The degree of irritation is a function of the concentration. Fluoride causes dental fluorosis (pitting and discoloration of the teeth) and crippling skeletal malformations. Additional concerns for this compound are neurotoxicity, mutagenicity, and possibly developmental toxicity. The uncertain concern for developmental toxicity is by analogy to ammonium chloride.	Moderate high
Aryl phenol	Expect moderate absorption by all routes. Moderate concerns for oncogenicity due to positive data; low moderate concerns for mutagenicity due to positive Ames and mouse lymphoma assays; low moderate concerns for renal effects and developmental and reproductive toxicity due to presence of phenolic moiety.	Moderate
Bismuth compound	Absorption is expected to be nil through the skin and good through the lungs and GI tract. In water, this compound will cause irritation of all moist tissues. There is also concern for neurotoxicity and possibly developmental toxicity. There is no concern for mutagenicity based on negative results for DNA damage. This compound has a relatively high oral LD50. [a]	Moderate, based on irritation
Citric acid	Expect poor absorption by skin, but expect absorption by lungs and GI tract. No health concerns identified.	Low

Chemical	SAT Health Effects Pertaining to Dermal or Inhalation Exposure	Overall Concern Level
Ethoxylated alkylphenol	Absorption is expected to be poor through the skin, moderate through the GI tract, and good through the lungs. As a surfactant, this compound may cause lung effects if inhaled. This compound is expected to be a severe and persistent eye irritant. Eye irritation is of particular concern because this type of compound can anesthetize the eye so an individual will not feel pain and rinse the material out of the eye. It is also expected to be irritating to the lungs. Possible signs of lung irritation (lung discoloration) were noted with a similar chemical tested in an acute inhalation study in rats. There is uncertain concern for reproductive effects and immunotoxicity. By analogy to a related compound, this chemical may be an endocrine disrupter. Liver and kidney effects were noted in rats with a structural analog. Myocardial degeneration has also been noted in several species with related compounds. Developmental toxicity as demonstrated by skeletal changes has been noted with dermal and oral exposure.	Low moderate
Fatty amine	Absorption is expected to be poor through the skin, moderate through the GI tract, and good through the lungs. This compound is expected to be a strong irritant and/or corrosive to exposed tissues. A similar compound was reported to be a moderate skin irritant and a severe eye irritant. Oleyl amine is a severe irritant. There is also concern for lung effects if inhaled. Another analog was tested in a subchronic gavage study in rats and dogs. Cataracts were noted in rats, stomach and lung lesions consistent with irritation were seen, and liver effects were seen in female dogs. There is concern for developmental toxicity. There is little concern for mutagenicity by analogy to a similar compound.	Moderate
Hydroxyaryl acid	Absorption is expected to be poor through the skin and good through the lungs and GI tract. There is concern for developmental toxicity and uncertain concern for effects on blood clotting (slower time for clotting). This compound is expected to have estrogenic activity. It has low acute toxicity. It may also cause neurotoxicity and hypersensitivity. There is some concern for mutagenicity.	Moderate
Hydroxyaryl sulfonate	Absorption is expected to be nil through the skin and good through the lungs and GI tract. There is concern for developmental toxicity. This compound is also expected to be an irritant (the free acid is corrosive to the eyes) and may cause neurotoxicity.	Low moderate
Maleic acid	Expect no absorption by skin, but expect absorption by lungs and GI tract. Maleic acid is reported to be negative in a NTP Ames assay. According to Merck this chemical is strongly irritating to corrosive.	Moderate

Chemical	SAT Health Effects Pertaining to Dermal or Inhalation Exposure	Overall Concern Level
Malic acid	Expect no absorption by skin, but expect absorption by lungs and GI tract. Concerns for mild irritation to skin and eyes.	Low moderate
Potassium compound	Absorption/corrosion by all routes. Concentrated form is corrosive to all tissues. Dilute form may be irritating. No other health concerns identified.	High for concentrated form only, otherwise low
Potassium peroxymonosulfate	Absorption is expected to be nil through the skin and good through the lungs and GI tract. The peroxymonosulfate moiety is reactive with moisture (oxidizing agent). This material will be an irritant as a concentrated solution.	Moderate
Quaternary alkylammonium chlorides	Absorption is expected to be poor through the skin, moderate through the GI tract, and good through the lungs. This chemical is expected to be a strong irritant and/or corrosive to all exposed tissues. It is also expected to be neurotoxic. There is also concern for lung effects if inhaled. There is concern for developmental toxicity as an ethanolamine derivative. This compound is expected to be in the moderately toxic range for acute toxicity.	Moderate
Sodium benzene sulfonate	Absorption is expected to be nil through the skin and good through the lungs and GI tract. There is concern for methemoglobinemia, neurotoxicity, and developmental toxicity. Serious brain damage was noted in a 2-week inhalation study with a related compound. There is uncertain concern for oncogenicity. This compound is reported to be negative in the Ames assay. It is expected to be irritating to mucous membranes and the upper respiratory tract.	Moderate concern
Sodium hypophosphite; Sodium hypophosphite monohydrate	Absorption is expected to be nil through the skin and good through the lungs and GI tract. This compound has low acute toxicity. It is irritating to mucous membranes and may cause dermal sensitization. There is uncertain concern for mutagenicity. It is reported to be effective in inhibiting the growth of selected Gram-positive pathogenic bacteria.	Low moderate concern
Substituted amine hydrochloride	Absorption is expected to be nil through the skin and good through the lungs and GI tract. This chemical has fairly high acute toxicity. It is a severe skin irritant in guinea pigs and a weak to moderate dermal sensitizer. In a repeated dose dietary study in rats, the primary effects were on the red blood cells (through methemoglobin production) and the spleen. This compound is reported to be positive in a variety of mutagenicity assays, although there are also some negative responses. There is concern for oncogenicity based on the mutagenicity results. There is uncertain concern for developmental toxicity.	Moderate concern

Chemical	SAT Health Effects Pertaining to Dermal or Inhalation Exposure	Overall Concern Level
Transition metal salt	Absorption is expected to nil through the skin and good through the lungs and GI tract. This compound is expected to be an irritant because it is hydroscopic. There is concern for mutagenicity. There is also concern for neurotoxicity and uncertain concern for allergic reactions.	Moderate concern

[a] LD50: Lethal dose to 50 percent of the test population.

Table 3-26. Overview of Available Toxicity Data

Chemical	Cancer: Slope Factor (SF), Weight-of-Evidence (WOE) Classification	Inhalation: RfC, NOAEL, or LOAEL [a]	Oral/Dermal: RfD, NOAEL, or LOAEL [a]	SAT Rank
1,4-Butenediol				X
Acetic acid			NOAEL	
Aliphatic acid A			Yes	
Aliphatic acid B				X
Aliphatic acid D		Yes	Yes	
Aliphatic acid E				
Aliphatic dicarboxylic acid A				X
Aliphatic dicarboxylic acid C			Yes	
Alkylalkyne diol				X
Alkylamino acid A				X
Alkylamino acid B				
Alkylaryl imidazole				X
Alkylaryl sulfonate				X
Alkyldiol		Yes	Yes	
Alkylimine dialkanol				X
Alkylphenol ethoxylate				X
Alkylphenol polyethoxyethanol				X
Alkylpolyol			Yes	
Amino acid salt				X
Amino carboxylic acid			Yes	
Ammonium chloride		RfC (for ammonia)	D-NOAEL RfD (for ammonium sulfamate)	
Ammonia compound A		RfC (for ammonia)	Yes	
Ammonia compound B		RfC (for ammonia)	Yes	X
Ammonium hydroxide		RfC (for ammonia)	RfD (for ammonium sulfamate)	

Chemical	Cancer: Slope Factor (SF), Weight-of-Evidence (WOE) Classification	Inhalation: RfC, NOAEL, or LOAEL [a]	Oral/Dermal: RfD, NOAEL, or LOAEL [a]	SAT Rank
Aromatic imidizole product	Not enough information to identify a specific chemical.			
Arylphenol			Yes	X
Bismuth compound				X
Citric acid [b]				X
Copper ion	WOE (for copper)	LOAEL	LOAEL; D-LOAEL	
Copper salt C	WOE (for copper)	Yes	Yes; D-LOAEL	
Copper sulfate pentahydrate	WOE (for copper)	LOAEL	LOAEL; D-LOAEL	
Cyclic amide		Yes	Yes	X
Ethoxylated alkylphenol				X
Ethylenediamine		NOAEL	RfD; D-LOAEL	
Ethylene glycol		LOAEL; D-NOAEL	RfD; D-NOAEL	
Ethylene glycol monobutyl ether		RfC	RfD; D-NOAEL	
Fatty amine				X
Fluoboric acid				X
Gum			Yes	
Hydrochloric acid	WOE	RfC		
Hydrogen peroxide	WOE	Other [b]	LOAEL	
Hydroxy carboxylic acid		Yes	Yes	X
Hydroxyaryl acid				X
Hydroxyaryl sulfonate				X
Inorganic metallic salt A	SF, WOE	Yes	Yes	
Inorganic metallic salt B		Yes	Yes	
Inorganic metallic salt C		Yes	Yes	
Lead	WOE	Other [b]	Other [b]	
Maleic acid				X
Malic acid [c]				X
Methane sulfonic acid				
Nickel sulfate	WOE (for nickel dust)	MRL [d]	RfD	
Nitrogen acid				
Nonionic surfactant	Not enough information to identify specific chemical.			
Palladium chloride	Some data (for Pd)			
Palladium salt	Some data (for Pd)			
Phosphoric acid		RfC	ADI [e]	
Potassium compound				X
Potassium gold cyanide			RfD [f]	
Potassium peroxymonosulfate				X

Chemical	Cancer: Slope Factor (SF), Weight-of-Evidence (WOE) Classification	Inhalation: RfC, NOAEL, or LOAEL [a]	Oral/Dermal: RfD, NOAEL, or LOAEL [a]	SAT Rank
Propionic acid	Some data	Other [c]	NOAEL	
Quantenary alkylammonium chlorides				X
Silver salt	WOE (for silver)		Yes	
Silver nitrate	WOE (for silver)		RfD (for silver)	
Sodium benzene sulfonate				X
Sodium hydroxide				
Sodium hypophosphite				X
Sodium hypophosphite mono hydrate				X
Sodium phosphorus salt				X
Sodium salt [g]				
Stannous methane sulfonic acid	WOE		RfD (for tin)	
Substituted amine hydrochloride				X
Sulfuric acid	WOE	Other [c]		
Surfactant	Not enough information to identify specific chemical.			
Thiourea	WOE			
Tin			RfD	
Tin chloride	WOE		RfD	
Transition metal salt				X
Unspecified tartrate			Yes	
Urea				
Urea compound B	WOE			
Urea compound C			Yes	
Vinyl polymer	WOE		Yes	

[a] "Yes" indicates a value is available (RfC or RfD, NOAEL or LOAEL) but the type of toxicity measure is not specified in order to protect confidential ingredient identity. D-NOAEL/or D-LOAEL: Developmental NOAEL or LOAEL available.

[b] Toxicity data other than RfD, NOAEL or LOAEL were used; see Tables 3-22 and 3-23 for details.

[c] Generally recognized as safe (GRAS) by the U.S. Food & Drug Administration (HSDB, 1995).

[d] MRL = minimal risk level.

[e] ADI = allowable daily intake.

[f] These values are only relevant to the oral route; potassium gold cyanide is expected to be chemically stable except under highly acidic conditions such as those found in the stomach (pH 1-2).

[g] Not generally considered poisonous to humans or animals.

3.3.3   Ecological Hazard Summary

Ecological hazards data are presented in two ways: through a CC and an aquatic hazard concern level, each derived separately from aquatic toxicity data (fish, invertebrates, and algae). Hazards to terrestrial species were not assessed because sufficient toxicity data were not available. CCs are based on the most sensitive endpoint, modified by an assessment factor, which reflects the amount and quality of toxicity data available for that chemical. CCs are compared to estimated surface water concentrations as part of the Risk Characterization (Section 3.4). Aquatic hazard concern levels are based on where the lowest available toxicity value (i.e., the most sensitive endpoint) fits into pre-defined ranges of values, indicating relative toxicity when compared to other chemicals.

Concern Concentration

Table 3-27 presents a summary of the available ecological hazards information. CCs were determined for aquatic species (e.g., *Daphnia*, algae, and/or fish) using standard EPA methodology. The method for determining CCs is summarized below and presented in more detail in Appendix H.

Table 3-27. Estimated (Lowest) Aquatic Toxicity Values and Concern Concentrations for PWB Surface Finishing Chemicals, Based on Measured Test Data or SAR Analysis

Chemical	Acute (a) Toxicity (mg/L)			Chronic (c) Toxicity (mg/L)			Concern Concentration (mg/L)
	Fish	Invert	Algae	Fish	Invert	Algae	
1,4-Butenediol	0.5			0.08			0.008 (c)
Acetic acid	79	65					0.65 (a)
Aliphatic acid A	data omitted [a]						0.5 - 1 (a)
Aliphatic acid B	data omitted [a]						1- 5 (c)
Aliphatic acid D	data omitted [a]						5 - 10 (c)
Aliphatic acid E	data omitted [a]						>1 (c)
Aliphatic dicarboxylic acid A	data omitted [a]						>1 (c)
Aliphatic dicarboxylic acid C	data omitted [a]						>10
Alkylalkyne diol	data omitted [a]						0.1 - 0.5 (c)
Alkylamino acid A	data omitted [a]						500 - 1,000 (c)
Alkylamino acid B	data omitted [a]						0.1 - 5 (c)
Alkylaryl imidazole	data omitted [a]						0.001 - 0.005 (c)
Alkylaryl sulfonate	data omitted [a]						0.001 - 0.005 (c)
Alkyldiol	data omitted [a]						10 - 50 (c)
Alkylimine dialkanol	data omitted [a]						0.001 - 0.005 (c)
Alkylphenol ethoxylate	data omitted [a]						0.1 - 0.5 (c)
Alkylphenol polyethoxyethanol	16	16	20	2	2	5	0.2 (c)
Alkylpolyol	data omitted [a]						5 - 10 (c)

Chemical	Acute (a) Toxicity (mg/L)			Chronic (c) Toxicity (mg/L)			Concern Concentration (mg/L)
	Fish	Invert	Algae	Fish	Invert	Algae	
Amino acid salt	data omitted [a]						0.5 - 1 (c)
Amino carboxylic acid	data omitted [a]						5 - 10 (c)
Ammonia compound A	data omitted [a]						1 - 5 (a)
Ammonia compound B	data omitted [a]						0.01 - 0.05 (c)
Ammonium chloride	725	161					1.6 (a)
Ammonium hydroxide	12	32	>30	1	3	>3	0.1 (c)
Arylphenol	data omitted [a]						0.01 - 0.05 (c)
Bismuth compound	data omitted [a]						0.1 - 0.5 (c)
Citric acid In soft water In hard water	>100	>100	5 100	>10	>10	1 30	0.1 (c) 3.0 (c)
Copper ion	0.14	12.8					0.001 (a)
Copper salt C	data omitted [a]						0.005 - 0.01(c)
Copper sulfate pentahydrate	0.34	0.3	0.00002	0.022	0.0014	0.062	0.01 (c)
Cyclic amide	data omitted [a]						10 - 50 (c)
Ethoxylated alkylphenol	data omitted [a]						0.1 - 0.5 (c)
Ethylenediamine	220	26.5	>100		0.16	8.3	0.02 (c)
Ethylene glycol	10,000	6,900	31,000	5,400	710	440	44 (c)
Ethylene glycol monobutyl ether [b]	116	89	620	10	3.9	32	0.04 (c)
Fatty amine	data omitted [a]						0.001 - 0.005 (c)
Fluoboric acid	>1,000	560	160	20	70	1.4	0.14 (c)
Gum	data omitted [a]						0.5 - 1 (c)
Hydrochloric acid	70	100	345	63	16	15	1.5 (c)
Hydrogen peroxide	5.9	4.3	1.7				0.02 (a)
Hydroxyaryl acid	data omitted [a]						0.1 - 0.5 (c)
Hydroxyaryl sulfonate	data omitted [a]						1 - 5 (c)
Hydroxy carboxylic acid	data omitted [a]						1 - 5 (c)
Inorganic metallic salt A	data omitted [a]						0.0001-0.0005 (c)
Inorganic metallic salt B	data omitted [a]						0.001 - 0.005 (c)
Inorganic metallic salt C	data omitted [a]						0.001 - 0.005 (c)
Lead	315	143	500	4.1	30		0.41 (c)
Maleic acid	5,227	1,199	30,654			993	99.3 (c)
Malic acid	2,860 g/L	2,380 g/L	1,200 g/L	204,000	24,378	14,339	1,434 (c)
Methane sulfonic acid	>1,000	>1,000	>1,000	>100	>100	>100	10 (c)
Nickel sulfate	1.28	2.58	1.9				0.01 (a)
Nitrogen acid	data omitted [a]						1 - 5 (c)
Palladium chloride	1,584	1,567	917	170	49	47	4.7 (c)

Chemical	Acute (a) Toxicity (mg/L)			Chronic (c) Toxicity (mg/L)			Concern Concentration (mg/L)
	Fish	Invert	Algae	Fish	Invert	Algae	
Palladium salt	data omitted [a]						1 - 5 (c)
Phosphoric acid	1,751	25,817	13,761	2,405	394	278	27.8 (c)
Potassium compound	data omitted [a]						1,000 - 1,500 (c)
Potassium gold cyanide	≥0.6	≥2	≥0.4	≥0.06	≥0.03	≥0.1	0.003 (c)
Potassium peroxymonosulfate	≤1	≤3	≤3	≤0.1	≤0.3	≤1	0.01 (c)
Propionic acid	1,369	587	6,644	1,216	318	292	29.2 (c)
Quantenary alkylammonium chlorides	data omitted [a]						0.01 - 0.05 (c)
Silver nitrate	0.007	0.0007	0.13	0.001	0.005		0.0001 (c)
Silver salt	data omitted [a]						0.0001 - 0.0005 (c)
Sodium benzene sulfonate	data omitted [a]						>1 (c)
Sodium hydroxide	133,000	191,000 g/L	3,180 g/L	498,000	22,658	10,616	1,062 (c)
Sodium hypophosphite and Sodium hypophosphite monohydrate	199,000 g/L	1,330 g/L	55,700 g/L	8,430 g/L	331,000	103,000	10,300 (c)
Sodium phosphorus salt	data omitted [a]						10,000 - 50,000 (c)
Sodium salt	data omitted [a]						50 - 100 (c)
Stannous methane sulfonic acid	7	140	≤ 8	0.2	0.9	≤ 0.8	0.02 (c)
Substituted amine hydrochloride	data omitted [a]						0.01 - 0.05 (c)
Sulfuric acid	42	5,200 g/L	250,000	600,000	4,222	2,241	224 (c)
Thiourea	>100	9	4.8	≥60	0.9	0.3	0.03(c)
Tin	2.7	55	≤3	0.07	0.35	≤0.3	0.007 (c)
Tin chloride	1.89	19.5	0.2	0.4	42		0.04 (c)
Transition metal salt	data omitted [a]						≤1 - 5 (c)
Unspecified tartrate	data omitted [a]						1 - 5 (c)
Urea	>1,000	>1,000	>1,000	>100	>100	>100	>10 (c)
Urea compound B	data omitted [a]						0.01 - 0.05 (c)
Urea compound C	data omitted [a]						0.01 - 0.05 (c)
Vinyl polymer	data omitted [a]						≥1 - 5

[a] Data omitted from table and a range reported for CC in order to protect identity of confidential ingredients.
[b] Diethylene glycol monobutyl ether reviewed instead; both chemicals are very similar.

The CC for each chemical in water was calculated using the general equation:

$$CC = \text{acute or chronic toxicity value} \div UF$$

where,

CC   =   aquatic toxicity concern concentration, the concentration of a chemical in the aquatic environment below which no significant risk to aquatic organisms is expected

UF   =   uncertainty factor, the adjustment value used in the calculation of a CC that incorporates the uncertainties associated with: 1) toxicity data (e.g., laboratory test versus field test, measured versus estimated data); 2) acute exposures versus chronic exposures; and 3) species sensitivity. This factor is expressed as an order of magnitude or as a power of ten (U.S. EPA, 1984).

If several acute or chronic toxicity values are available, the lowest one is used (most sensitive tested species), unless poor or uncertain data quality disqualify one or more of the values. UFs are dependent on the amount and type of toxicity data contained in a toxicity profile and reflect the amount of uncertainty about the potential effects associated with a toxicity value. In general, the more complete the toxicity profile and the greater the quality of the toxicity data, the smaller the UF used.

The following approach was used, depending on availability and type of data:

C   If the toxicity profile only contained one or two acute toxicity values (no chronic values), UF = 1,000 and the CC was calculated by using the lower acute value.

C   If the toxicity profile contained three or more acute values (no chronic values), UF = 100 and the CC was calculated by using the lowest acute value.

C   If the toxicity profile contained at least one chronic value, and the value was for the most sensitive species, UF = 10 and the CC was calculated by using the lowest chronic value; otherwise, UF = 100 and the CC was calculated with the acute value for the most sensitive species.

Hazard Concern Levels

Table 3-28 presents aquatic hazard concern levels; chemicals were assigned to aquatic toxicity concern levels according to the following EPA criteria:

For chronic values:
> $\leq$ 0.1 mg/L.................High concern
> > 0.1 to # 10 mg/L.....Moderate concern
> > 10 mg/L...................Low concern

For acute values:
> $\leq$ 1 mg/L....................High concern
> > 1 to # 100 mg/L......Moderate concern
> > 100 mg/L.................Low concern

Chronic toxicity ranking takes precedence over the acute ranking.

Most surface finishing chemicals can theoretically be subject to spills and releases. Also, PWB facilities routinely release wastewater to POTWs. Different geographic regions and different POTWs have different levels of acceptability for such wastes, and the acceptable levels can change over time. Discontinuing use of chemicals in Table 3-28 with Medium to High hazard concern levels can help avoid potential problems.

Table 3-28. Environmental Hazard Ranking of PWB Finishing Chemicals

Chemical	Lowest Acute (a) or Chronic (c) Value (mg/L)	Hazard Rank [a]
1,4-Butenediol	0.08 (c)	H
Acetic acid	65 (a)	L
Aliphatic acid A	NR	L
Aliphatic acid B	NR	L
Aliphatic acid D	NR	L
Aliphatic acid E	NR	L
Aliphatic dicarboxylic acid A	NR	L
Aliphatic dicarboxylic acid C	NR	L
Alkylalkyne diol	NR	M
Alkylamino acid A	NR	L
Alkylamino acid B	NR	M
Alkylaryl imidazole	NR	H
Alkylaryl sulfonate	NR	H
Alkyldiol	NR	L
Alkylimine dialkanol	NR	H
Alkylphenol ethoxylate	NR	M to H [b]
Alkylphenol polyethoxyethanol	0.008 (c) to 2 (c)	M to H [b]
Alkylpolyol	NR	L
Amino acid salt	NR	L
Amino carboxylic acid	NR	L
Ammonia compound A	NR	L
Ammonia compound B	NR	H
Ammonium chloride	161(a)	L
Ammonium hydroxide	1 (c)	M
Arylphenol	NR	M
Bismuth compound	NR	M
Citric acid	1 (c)	M
Copper ion	0.14 (a)	H
Copper salt C	NR	H
Copper sulfate pentahydrate	0.001(c)	H
Cyclic amide	NR	L
Ethoxylated alkylphenol	NR	M to H [b]

Chemical	Lowest Acute (a) or Chronic (c) Value (mg/L)	Hazard Rank [a]
Ethylenediamine	0.16 (c)	M
Ethylene glycol	440 (c)	L
Ethylene glycol monobutyl ether [c]	3.9 (c)	M
Fatty amine	NR	H
Fluoboric acid	1.4 (c)	M
Gum	NR	L
Hydrochloric acid	15 (c)	M
Hydrogen peroxide	1.7 (a)	M
Hydroxyaryl acid	NR	M
Hydroxy aryl sulfonate	NR	L
Hydroxy carboxylic acid	NR	L
Inorganic metallic salt A	NR	H
Inorganic metallic salt B	NR	H
Inorganic metallic salt C	NR	H
Lead	4.1 (c)	M
Maleic acid	993 (c)	L
Malic acid	14,339 (c)	L
Methane sulfonic acid	>100 (c)	L
Nickel sulfate	1.3 (a)	M
Nitrogen acid	NR	L
Palladium chloride	47 (c)	L
Palladium salt	NR	L
Phosphoric acid	278 (c)	L
Potassium compound	NR	L
Potassium gold cyanide	$\geq$0.03 (c)	H
Potassium peroxymonosulfate	$\leq$0.1 (c)	H
Propionic acid	292 (c)	L
Quantenary alkylammonium chlorides	NR	M
Silver nitrate	0.001 (c)	H
Silver salt	NR	H
Sodium benzene sulfonate	NR	L
Sodium hydroxide	10,616 (c)	L
Sodium hypophosphite and Sodium hypophosphite monohydrate	103,000 (c)	L
Sodium phosphorus salt	NR	L
Sodium salt	NR	L
Stannous methane sulfonic acid	0.2 (c)	M
Substituted amine hydrochloride	NR	M
Sulfuric acid	2,241 (c)	L

Chemical	Lowest Acute (a) or Chronic (c) Value (mg/L)	Hazard Rank [a]
Thiourea	0.3 (c)	M
Tin	0.07 (c)	H
Tin chloride	0.4 (c)	M
Transition metal salt	NR	M
Unspecified tartrate	NR	L
Urea	>100 (c)	L
Urea compound B	NR	M
Urea compound C	NR	M
Vinyl polymer	NR	L

[a] Ranking based on the lowest estimated acute or chronic value; H = high, M = medium, L = low.
[b] Toxicity of breakdown product results in high hazard rank.
[c] Diethylene glycol monobutyl ether reviewed instead; both chemicals are very similar.
NR: Not reported in order to protect confidential ingredient identity.

3.3.4   Summary

For human health hazards, toxicity data in the form of RfDs, RfCs, NOAELs, LOAELs, and cancer slope (cancer potency) factors were compiled for inhalation and dermal pathways. Inorganic metallic salt A (a confidential ingredient used in the nickel/gold process) was the only chemical with an established cancer slope (cancer potency) factor. Other chemicals in the surface finishing processes are carcinogens or suspected carcinogens, but do not have established slope factors. Strong inorganic acid mist of sulfuric acid has been determined by IARC to be a human carcinogen (IARC Group 1). Sulfuric acid is used in every surface finishing process in this evaluation. It is not expected, however, to be present as a strong acid mist because it is greatly diluted in the aqueous baths. Lead and thiourea have been determined by IARC to be possible human carcinogens (IARC Group 2B) and lead has also been classified by EPA as a probable human carcinogen (EPA Class B2). Lead is used in tin-lead solder in the HASL process. Thiourea is used in the immersion tin process. Urea compound B, a confidential ingredient in the nickel/gold and nickel/palladium/gold processes, is possibly carcinogenic to humans.

A total of 83 chemicals are considered as part of the surface finishing use cluster. For non-cancer health effects, eight surface finishing chemicals have inhalation RfCs available from which to calculate hazard quotient (HQ) in the risk characterization. For the remaining chemicals, 12 have an inhalation NOAEL or LOAEL from which to calculate margin of exposure (MOE). Pertaining to dermal exposure, 12 surface finishing chemicals have RfDs from which to calculate HQs; of the remaining chemicals, 19 have an oral NOAEL or LOAEL from which to calculate MOE. For a number of chemicals, no quantitative risk indicator could be calculated for direct comparison of risk among alternatives. A qualitative assessment was done for 33 chemicals, based on chemical structure, for which no quantitative non-cancer health effects measures were available.

An ecological hazards assessment was performed based on chemical toxicity to aquatic organisms. CCs were estimated for surface finishing chemicals using an established EPA method. A CC is an acute or chronic toxicity value divided by a UF. UFs are dependent on the amount and type of toxicity data contained in a toxicity profile and reflect the amount of uncertainty about the potential effects associated with a toxicity value. CCs were determined for aquatic species (e.g., *Daphnia*, algae, and/or fish). CCs are compared to estimated surface water concentrations modeled from PWB wastewater releases in Section 3.4.

Chemicals were also ranked for aquatic toxicity concern levels using established EPA criteria (high, moderate, and low concern) based on the available toxicity data. The number of chemicals with a high aquatic hazard concern level include eight in the HASL process, nine in nickel/gold, five in nickel/palladium/gold, five in OSP, three in immersion silver, and six in the immersion tin process.

3.4   RISK CHARACTERIZATION

Risk characterization integrates the hazard and exposure components of a risk evaluation and presents overall conclusions. Risk characterization typically includes a description of the assumptions, scientific judgments, and uncertainties that are part of this process. The focus of this risk characterization is on chronic (long-term) exposure to chemicals that may cause cancer or other toxic effects, rather than on acute toxicity from brief exposures to chemicals. The focus is also on those health effects from chronic exposures that could be used to measure risk. From an ecological risk standpoint, the focus is on chronic exposure to chemicals that cause sublethal effects (e.g., effects on growth and reproduction). The Process Safety Assessment (Section 3.5) includes further information on chemical safety concerns for workers.

The goals of the PWB project risk characterization are to:

C   present conclusions and uncertainties associated with a screening-level health risk assessment of chemicals used in the surface finishing process of PWB manufacture;
C   integrate chemical hazard and exposure information to assess potential risks from ambient environment and occupational exposures from the surface finishing process;
C   use reasonable and consistent assumptions across alternatives, so potential health risks associated with one alternative can be compared to the potential health risks associated with other alternatives; and
C   identify the areas of concern that differ among the substitutes in a manner that facilitates decision-making.

This section contains a summary of the exposure assessment (Section 3.4.1), a summary of the human health hazards assessment (Section 3.4.2), and the ecological hazards assessment (Section 3.4.3), a description of methods used to calculate risk indicators (Section 3.4.4), potential human health risk results (Section 3.4.5), an evaluation of lead risks from tin-lead solder used in the HASL process (Section 3.4.6), ecological (aquatic) risk results (Section 3.4.7), a discussion of uncertainties (Section 3.4.8), and conclusions (Section 3.4.9). Detailed exposure and hazard data are presented separately in the Exposure Assessment (Section 3.2) and Human Health and Ecological Hazards Summary (Section 3.3), respectively.

3.4.1   Summary of Exposure Assessment

The exposure assessment uses a "model facility" approach where, as much as possible, reasonable and consistent assumptions are used across alternatives. Data to characterize the model facility and exposure patterns for each process alternative were aggregated from a number of sources, including PWB shops in the U.S. and abroad, supplier data, and input from PWB manufacturers at project meetings. Thus, the model facility is not entirely representative of any one facility, and actual exposure (and risk) could vary substantially, depending on site-specific operating conditions and other factors.

Chemical exposures to PWB workers and the general population were estimated by combining information gathered from industry (PWB Workplace Practices Questionnaire and Performance Demonstration data, MSDSs, other information provided by product suppliers, and other available information) with standard EPA exposure assumptions (e.g., for inhalation rate, surface area of dermal contact, and other parameters). The pathways for which potential exposure from surface finishing process baths was quantified include inhalation and dermal contact for workers, inhalation for the general population living near a PWB facility, and contact with aquatic organisms living in a stream that receives treated wastewater originating from a PWB facility. Acute impacts, such as impacts from chemical spills, are not addressed due to the pre-defined scope of this assessment.

Inhalation exposure could occur by breathing air containing vapor or aerosol-phase chemicals from the surface finishing process line. Inhalation exposures to workers from non-conveyorized lines are estimated in the exposure assessment. Inhalation exposure to workers from conveyorized surface finishing lines is much lower than for non-conveyorized lines because the lines are typically enclosed and vented to the outside.[15] The model used to estimate daily inhalation exposure is from the EPA *Chemical Engineering Branch Manual for the Preparation of Engineering Assessments* (U.S. EPA, 1991a):

$$I = (Cm)(b)(h)$$

where,

I	=	daily inhalation potential dose rate (mg/day)
Cm	=	airborne concentration of substance (mg/m^3)
b	=	inhalation rate (m^3/hr)
h	=	duration (hr/day)

Daily exposures are then averaged over a lifetime (70 years) for carcinogens, and over the exposure duration (e.g., 25 years working in a facility) for non-carcinogens,[16] using the following equations:

For carcinogens:

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[15] Inhalation exposures for conveyorized process configurations were initially assumed to be negligible, and are not presented separately here. Some inhalation exposure is possible, however, during sampling and bath replacement, when the baths are opened for a short period of time. After characterizing risks from inhalation for non-conveyorized lines, inhalation exposures and risks were estimated for the subset of inhalation chemicals of concern for conveyorized lines. No chemical exposures from inhalation resulted in risks above concern levels for conveyorized lines.

[16] Different averaging times are used for characterizing risk for carcinogenic and non-carcinogenic effects. For carcinogenic agents, because even a single incidence of exposure is assumed to have the potential to cause cancer throughout an individual's lifetime, the length of exposure to that agent is averaged over a lifetime. An additional factor is that the cancer latency period may extend beyond the period of working years before it is discernible. For chemicals exhibiting non-cancer health effects from chronic (longer-term) exposure, where there is an exposure threshold (a level below which effects are not expected to occur), only the time period when exposure is occurring is assumed to be relevant and is used as the averaging time.

$$LADD = (I)(EF)(ED)/[(BW)(AT_{CAR})]$$

For non-carcinogens:

$$ADD = (I)(EF)(ED)/[(BW)(AT_{NC})]$$

where,

LADD	=	lifetime average daily dose (mg/kg-day)
ADD	=	average daily dose (mg/kg-day)
EF	=	exposure frequency (days/year)
ED	=	exposure duration (years)
BW	=	body weight (kg)
AT_{CAR}	=	averaging time for carcinogenic effects (days)
AT_{NC}	=	averaging time for non-carcinogenic chronic effects (days)

The daily intake for inhalation exposure to workers was calculated by first modeling chemical emissions from surface finishing baths with three air-transport mechanisms: liquid surface diffusion (desorption), bubble desorption, and aerosol generation and ejection. This modeled chemical emission rate was combined with data from the PWB Workplace Practices Questionnaire and Performance Demonstration Data Sheets regarding process room size and air turnover rate to estimate an average indoor air concentration for the process area.

Modeled air concentrations were used to evaluate inhalation exposure to a nearby population. This outdoor air modeling used the air emission rates that were estimated for the process baths, assuming they are vented outside at the same rate they are emitted from the baths. The Industrial Source Complex - Long Term (ISCLT) air dispersion model[17] was used to estimate air concentrations resulting from dispersion in the outdoor air. The modeled air concentrations of each contaminant were determined at 100 meters radially from a PWB facility. The highest estimated air concentration was used to estimate inhalation exposure to a hypothetical population located near a model PWB facility. Inhalation exposures estimated for the public living 100 meters away from a PWB facility were very low (approximately 10,000 times lower than occupational exposures).

Dermal exposure could occur when skin comes in contact with the bath solution while dipping boards, adding bath replacement chemicals, etc. Although the data suggest that most surface finishing line operators wear gloves for many activities, it was assumed in this evaluation that workers do not wear gloves, to account for the fraction that do not. Otherwise, dermal exposure is expected to be negligible. For dermal exposures, the flux of a material through the skin was estimated based on U.S. EPA, 1992a:

$$D = (S)(C)(f)(h)(0.001)$$

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[17] This version of the ISCLT model is provided as part of the Risk*Assistant™ 2.0 software package (Hampshire Research Institute, 1995).

where,

D   =   dermal potential dose rate (mg/day)
S   =   surface area of contact (cm^2)
C   =   concentration of chemical in the bath (mg/L)
f   =   flux through skin (cm/hour)
h   =   duration (hours/day) with a conversion factor of 0.001 (L/cm^3)

It should be noted that the above equation was developed for exposures with an infinite volume of liquid or boundary layer contacting the skin, such as swimming or bathing. Occupational conditions of dermal contact are likely to be more finite in comparison, resulting in possible overestimates of flux through the skin when using the above equation.

Similar to inhalation, daily dermal exposures were then averaged over the exposure duration for non-carcinogens (cancer risk was not quantified because none of the surface finishing chemicals have an oral or dermal cancer slope factor) using the following equation:

$$ADD = (D)(EF)(ED)/[(BW)(AT_{NC})]$$

For dermal exposure, the concentration of chemical in the bath and duration of contact for workers was obtained from publicly-available bath chemistry data, disclosed proprietary chemical information, supplier data sheets, and PWB Workplace Practices Questionnaire information. A permeability coefficient (rate of penetration through skin) was estimated for organic compounds and a default rate assumption was used for inorganic chemicals. Reliance on such estimates in the absence of data is a source of uncertainty in the exposure assessment.

Key assumptions in the exposure assessment include the following:

C   The exposure frequency (i.e., days/year of line operation) was based on the time required to manufacture 260,000 ssf of PWB.

C   For dermal exposure, it was assumed that line operators do not wear gloves. Although the data suggest that many surface finishing line operators do wear gloves for various activities, it was assumed for this evaluation that workers do not wear gloves, to account for the subset of workers who do not wear proper personal protective equipment.

C   For dermal exposure, it was assumed that all non-conveyorized lines are manual hoist.

C   The worker on a non-conveyorized line is assumed to potentially have dermal contact for the entire time spent in the surface finishing process area, and the contact time is assumed to be divided equally among the baths over an 8-hour workday. This does not mean that a worker has both hands immersed in a bath for that entire time but that the skin is in contact with bath solution (i.e., the hands may remain wet from contact). This assumption may result in an overestimate of dermal exposure.

C   For estimating ambient (outdoor) air concentrations, it was assumed that no air pollution control technologies are used to remove airborne chemicals from facility air prior to venting it to the outside.

C For inhalation exposure to workers, it was assumed that chemical emissions to air in the process room from conveyorized lines are negligible, and that no vapor control devices (e.g., bath covers) are used on baths in non-conveyorized lines.

C For air concentrations, the model assumes complete mixing in the process room and that concentrations do not change with time (i.e., steady state).

C For all exposures, it was assumed that there is one surface finishing process line and one line operator per shift in a process area.

C For characterizing the chemical constituents in the surface finishing process baths, it was assumed that the form (speciation) and concentration of all chemicals in the baths are constant over time.

Chemical concentrations in baths are based on publicly-available chemistry data, including MSDSs, proprietary chemical information, and supplier Product Data Sheets that describe how to mix and maintain chemical baths. Many MSDSs provided concentration ranges for chemical constituents instead of absolute concentrations, in which case it was assumed that a chemical is present at the mid-point of the reported concentration range. This assumption may either overestimate or underestimate risk for chemicals, depending on their actual concentrations.

Assumptions and parameter values used in these equations, and results of the exposure calculations, are presented in the Exposure Assessment (Section 3.2). In order to provide information about the position an exposure estimate has in the distribution of possible outcomes, exposure (or risk) descriptors are used following EPA's *Guidelines for Exposure Assessment* (U.S. EPA, 1992b). For this risk characterization, whenever possible the exposure assessment uses a combination of central tendency (either an average or median estimate) and high-end (90th percentile)[18] assumptions, as would be used for an overall high-end exposure estimate. The 90th percentile is used for:

C hours per day of workplace exposure;

C exposure frequency;

C exposure duration in years (90th percentile for occupational and 95th percentile for residential exposures);

C time required for chemical bath replacement;

C time and frequency of filter replacements, conveyor equipment cleaning, and chemical bath sampling (minutes per occurrence and number of occurrences per year); and

C estimated workplace air concentrations.

Average values are used for:

C body weight;

C concentration of chemical in bath;

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[18] For exposure data from the PWB Workplace Practices Questionnaire, this means that 90 percent of the facilities reported a lower value, and ten percent reported a higher value.

C   frequency of chemical bath replacements;
C   number of baths in a given process; and
C   bath size.

Some values used in the exposure calculations, however, are better characterized as "what-if," especially pertaining to use of gloves, process area ventilation rates, and production times (days/year) required to manufacture 260,000 ssf of PWB for the model facility. ("What-if" represents an exposure estimate based on postulated questions, making assumptions based on limited data where the distribution is unknown.) Because some part of the exposure assessment for both inhalation and dermal exposures qualifies as a "what-if" descriptor, the entire assessment should be considered "what-if."

3.4.2   Summary of Human Health Hazards Assessment

For human health hazards, toxicity data in the form of RfDs, RfCs, NOAELs, LOAELs, and cancer slope (cancer potency) factors were compiled for inhalation and dermal pathways. Inorganic metallic salt A (a confidential ingredient used in the nickel/gold process) was the only chemical with an established cancer slope (cancer potency) factor. Other chemicals in the surface finishing processes are known or suspected carcinogens, but do not have established slope factors. Strong inorganic acid mist of sulfuric acid has been determined by IARC to be a human carcinogen (IARC Group 1). Sulfuric acid is used in every surface finishing process in this evaluation. It is not expected, however, to be present as a strong acid mist because it is greatly diluted in the aqueous baths. Lead and thiourea have been determined by IARC to be possible human carcinogens (IARC Group 2B) and lead has also been classified by EPA as a probable human carcinogen (EPA Class B2). Lead is used in tin-lead solder in the HASL process. Thiourea is used in the immersion tin process. Urea compound B, a confidential ingredient in the nickel/gold and nickel/palladium/gold processes, is possibly carcinogenic to humans.

3.4.3   Summary of Ecological Hazards Assessment

An ecological hazard assessment was performed based on chemical toxicity to aquatic organisms. CCs were estimated for surface finishing chemicals using an established EPA method (see Table 3-27 and Appendix H). A CC is an acute or chronic toxicity value divided by a UF. UFs are dependent on the amount and type of toxicity data contained in a toxicity profile, and reflect the amount of uncertainty about the potential effects associated with a toxicity value. Concern concentrations were determined for aquatic species (e.g., *Daphnia*, algae, and/or fish) for each chemical. The lowest CCs are for inorganic metallic salt A, silver nitrate, and silver salt. Chemicals also were ranked for aquatic toxicity concern levels using established EPA criteria (high, moderate, and low concern) based on the available toxicity data (see Table 3-28). The number of chemicals with a high aquatic hazard concern level include eight in the HASL process, nine in nickel/gold, five in nickel/palladium/gold, five in OSP, three in immersion silver, and six in the immersion tin process.

3.4.4 Methods Used to Calculate Human Health Risks

Estimates of potential human health risk from chemical exposure are characterized here in terms of excess lifetime cancer risk, HQ, and MOE. This section defines these risk indicators and discusses the methods for calculating each of them.

Cancer Risk

Cancer risks are expressed as the excess probability of an individual developing cancer over a lifetime from chemical exposure. For chemicals classified as carcinogens, an upper bound excess lifetime cancer risk, expressed as a unitless probability, was estimated by the following equation:

$$\text{Cancer Risk} = \text{LADD} \times \text{slope factor}$$

where,

Cancer Risk = the excess probability of developing cancer over a lifetime as a result of exposure to a potential carcinogen. The estimated risks are the upper bound excess lifetime cancer risks for an individual. (*Upper bound* refers to the method of determining a slope factor, where the upper bound value for the slope of the dose-response curve is used. *Excess* means the estimated cancer risk is in addition to the already-existing background risk of an individual contracting cancer from all other causes.)

LADD = the lifetime average daily dose, the estimated potential daily dose rate received during the exposure duration, averaged over a 70-year lifetime (in mg/kg-day). LADDs were calculated in the Exposure Assessment (Section 3.2).

Slope factor (q_1 *) is defined in Section 3.3.1.

Non-Cancer Risk Indicators

Non-cancer risk estimates are expressed either as an HQ or as an MOE, depending on whether or not RfDs and RfCs are available. There is a higher level of confidence in the HQ than the MOE, especially when the HQ is based on an RfD or RfC that has been peer-reviewed by EPA (as with data from the EPA IRIS database). If an RfD or RfC is available, the HQ is calculated to estimate risk from chemicals that exhibit chronic, non-cancer toxicity. (RfDs and RfCs are defined in Section 3.3.2.) The HQ is the unitless ratio of the RfD (or RfC) to the potential dose rate. For surface finishing chemicals that exhibit non-cancer toxicity, the HQ was calculated by:

$$\text{HQ} = \text{ADD/RfD}$$

where,

ADD = average daily dose rate, the amount of a chemical ingested, inhaled, or applied to the skin per unit time, averaged over the exposure duration (in mg/kg-day)

ADDs were calculated in the Exposure Assessment (Section 3.2).

The HQ is based on the assumption that there is a level of exposure (i.e., the RfD or RfC) below which it is unlikely, even for sensitive subgroups, to experience adverse health effects. Unlike cancer risk, the HQ does not express *probability* and is not necessarily linear; that is, an HQ of ten does not mean that adverse health effects are ten times more likely to occur than for an HQ of one. However, the ratio of estimated dose to RfD/RfC reflects the level of concern.

For chemicals where an RfD or RfC was not available, an MOE was calculated by:

$$MOE = NOAEL/ADD \text{ or } LOAEL/ADD$$

As with the HQ, the MOE is not a probabilistic statement of risk. The ratio for calculating MOE is the inverse of the HQ, so that a high HQ (exceeding one) indicates a potential concern, whereas a high MOE (exceeding 100 for a NOAEL-based MOE or 1,000 for a LOAEL-based MOE) indicates a low concern level. (NOAELS and LOAELs are defined in Section 3.3.2.) As the MOE increases, the level of concern decreases. (As the HQ increases, the level of concern also increases.) In general, there is a higher level of confidence for HQs than for MOEs because the toxicity data on which RfDs and RfCs are based have passed a more thorough level of review, and test-specific uncertainty factors have been included.

Both the exposure estimates and toxicity data are specific to the route of exposure (i.e., inhalation, oral, or dermal). Very few RfDs, NOAELs, or LOAELs are available for dermal exposure. If oral data were available, the following adjustments were made to calculate dermal values based on EPA (1989) guidance:

$$RfD_{DER} = (RfD_{ORAL}) (GI \text{ absorption})$$
$$NOAEL/LOAEL_{DER} = (NOAEL \text{ or } LOAEL_{ORAL}) (GI \text{ absorption})$$
$$SF_{DER} = (SF_{ORAL})/(GI \text{ absorption})$$

where,

RfD_{DER} = reference dose adjusted for dermal exposure (mg/kg-day)

$NOAEL/LOAEL_{DER}$ = NOAEL or LOAEL adjusted for dermal exposure (mg/kg-day)

SF_{DER} = cancer slope factor adjusted for dermal exposure $(mg/kg\text{-}day)^{-1}$

GI absorption = gastrointestinal absorption efficiency

This adjustment is made to account for the fact that the oral RfDs, NOAELs, and LOAELs are based on an applied dose, while dermal exposure represents an estimated absorbed dose. The oral RfDs, NOAELs, and LOAELs used to assess dermal risks therefore were adjusted using GI absorption to reflect an absorbed dose. Table 3-29 lists the GI absorption data for chemicals used in calculating risk from dermal exposure. (Data for some proprietary ingredients are not presented in order to protect confidential chemical identities.)

Table 3-29. Gastrointestinal (GI) Absorption Factors

Chemicals [a]	GI Absorption Factor	Source
Acetic acid	0.9	chemical profile [b]
Aliphatic acid A	0.9	chemical profile [b]
Aliphatic acid D	0.5	NR
Aliphatic dicarboxylic acid C	0.2	assumption [c]
Alkyldiol	NR	NR
Alkylpolyol	0.2	assumption [c]
Amino carboxylic acid	0.2	assumption [c]
Ammonia compound A	0.9	chemical profile [b]
Ammonia compound B	0.9	chemical profile [b]
Ammonium chloride	0.9	chemical profile [b]
Ammonium hydroxide	0.9	chemical profile [b]
Aryl phenol	0.5	chemical profile [b]
Copper ion, Copper salt C, and Copper sulfate pentahydrate	0.6	midpoint of range, 0.15 - 0.97; U.S. EPA, 1984
Cyclic amide	0.5	chemical profile [b]
Ethylene glycol	0.5	midpoint of range; HSDB, 1998
Ethylene glycol monobutyl ether	0.5	ATSDR, 1998
Ethylenediamine	0.78	midpoint of range, 0.6 - 0.95 U.S. EPA, 1988b
Hydroxy carboxylic acid	0.2	assumption [c]
Hydrogen peroxide	0.2	assumption [c]
Inorganic metallic salt A	NR	NR
Inorganic metallic salt B	0.15	NR
Inorganic metallic salt C	0.15	NR
Nickel sulfate	0.05	midpoint of range, 0.01 - 0.1, chemical profile
Phosphoric acid	0.2	U.S. EPA, 1995
Potassium gold cyanide	0.2	assumption [c]
Propionic acid	0.2	assumption [c]
Silver nitrate	0.08	midpoint of range, 0.05 - 0.1 (U.S. EPA, 1991c; ATSDR, 1990b)
Silver salt	NR	NR
Stannous methane sulfonic acid	0.2	assumption [c]
Tin chloride	0.5	Johnson and Greger, 1982
Unspecified tartrate	0.5	chemical profile [b]

Chemicals [a]	GI Absorption Factor	Source
Urea compound C	0.2	assumption [c]
Vinyl polymer	0.1	chemical profile [b]

[a] Includes only chemicals for which dermal HQs or MOEs could be calculated.
[b] Good, moderate, and low GI absorption, as reported in EPA chemical profiles, were translated to assumed GI absorption fractions of 0.9, 0.5, and 0.1, respectively.
[c] An assumption of 20 percent GI absorption was made for chemicals with no available GI absorption data.
NR: Not reported; data for some proprietary ingredients are not presented in order to protect confidential chemical identities.

Lead

Methods used to evaluate potential lead risks from tin-lead solder used in the HASL process are described in Section 3.4.6.

3.4.5   Results of Calculating Human Health Risk Indicators

This section presents the results of calculating risk indicators for both the occupational setting and the ambient (outdoor) environment. When considering these risk characterization results, it should be remembered that the results are intended for use in comparing relative potential risk between processes, based on a model PWB facility, and should not be used as absolute indicators of actual health risks to surface finishing line workers or to the public.

Occupational Setting

Estimated cancer risks and non-cancer risk indicators from occupational exposure to surface finishing chemicals are presented below. It should be noted that no epidemiological studies of health effects among PWB workers were located.

Inhalation Cancer Risk. Nickel/gold is the only process containing a chemical for which a cancer slope (cancer potency) factor is available. Inorganic metallic salt A, in the nickel/gold process, is the only chemical for which an inhalation cancer risk has been estimated. This metal compound is considered a human carcinogen.[19]

Inhalation exposure estimates are based on the assumptions that emissions to indoor air from conveyorized lines are negligible, that the air in the process room is completely mixed and chemical concentrations are constant over time, and that no vapor control devices (e.g., bath covers) are used in non-conveyorized lines. The exposure estimates use 90th percentile modeled air concentrations, which means that, based on the PWB Workplace Practices Questionnaire data and available information on bath concentrations, approximately 90 percent of the facilities are

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[19] A cancer classification of known human carcinogen has been assigned by either the EPA, IARC, and/or the National Toxicology Program (NTP). Further details about the carcinogen classification are not provided in order to protect the confidential chemical's identity.

expected to have lower air concentrations and, therefore, lower risks. Using 90th percentile data is consistent with EPA policy for estimating upper-bound exposures.

The upper bound maximum individual cancer risk over a lifetime is 2×10^{-7} based on a workplace concentration of 2.4×10^{-6} milligrams inorganic metallic salt A per cubic meter of air, over an 8 hour-day, for line operators using the non-conveyorized nickel/gold process. Cancer risks less than 1×10^{-6} (one in one million) are generally considered to be of low concern. The use of modeled, steady state, workplace air concentrations instead of actual monitoring data of average and peak concentrations thus emerges as a significant source of uncertainty in estimating cancer risk to workers exposed to inorganic metallic salt A in this industry. The available toxicological data do not indicate that dermal exposure to inorganic metallic salt A increases cancer risk, but no dermal cancer studies were located.

Risks to other workers would be proportional to the amount of time spent in the process area. The exposure from inhalation for a typical line operator is based on spending 8 hr/day in the surface finishing process area. Exposure times (i.e., time spent in the process area) for various worker types from the workplace practices database are listed below. The number in parentheses is the ratio of average time for that worker type to the 8 hr/day exposure time for a line operator.

C laboratory technician: 2.8 hr/day (0.35);
C maintenance worker: 1.6 hr/day (0.2);
C supervisor: 5.5 hr/day (0.69); and
C wastewater treatment operator: 1 hr/day (0.12).

(Other types of workers may be in the process area for shorter or longer times.)

Other Potential Cancer Risk. Slope factors (cancer potency values) are needed to calculate estimates of cancer risk. In addition to the chemical discussed above, lead and thiourea have been determined by IARC to be possible human carcinogens (IARC Group 2B); lead has also been classified by EPA as a probable human carcinogen (EPA Class B2). Lead is used in tin-lead solder in the HASL process. Thiourea is used in the immersion tin process. Urea compound B, a confidential ingredient in the nickel/gold and nickel/palladium/gold processes, is possibly carcinogenic to humans. There are potential cancer risks to workers from these chemicals, and workplace exposures have been estimated, but cancer potency and cancer risks are unknown. Additionally, strong inorganic acid mists of sulfuric acid have been determined by IARC to be a human carcinogen (IARC Group 1). Sulfuric acid is used in every surface finishing process in this evaluation. It is not expected, however, to be present as a strong acid mist because it used in diluted form in the aqueous baths.

Non-Cancer Risk. HQs and MOEs were calculated for line operators and laboratory technicians from workplace exposures. An HQ exceeding one indicates a potential concern. Unlike cancer risk, the HQ does not express probability, only the ratio of the estimated dose to

the RfD or RfC, and it is not necessarily linear (an HQ of ten does not mean that adverse health effects are ten times more likely than an HQ of one).

EPA considers high MOE values, such as values greater than 100 for a NOAEL-based MOE or 1,000 for a LOAEL-based MOE, to pose a low level of concern (Barnes and Dourson, 1988). As the MOE decreases, the level of concern increases. Chemicals are noted here to be of potential concern if a NOAEL-based MOE is lower than 100, a LOAEL-based MOE is lower than 1,000, or an MOE based on an effect level that was not specified as a LOAEL (used in the absence of other data) is less than 1,000. As with the HQ, it is important to remember that the MOE is not a probabilistic statement of risk.

Inhalation risk indicators of concern are presented in Table 3-30. This includes chemicals of potential concern based on MOE and/or HQ results, as well as cancer risk results for the one chemical with a cancer slope factor. Inhalation exposure estimates are based on the assumptions that emissions to air from conveyorized lines are negligible, that the air in the process room is completely mixed and chemical concentrations are constant over time, and that no vapor control devices (e.g., bath covers) are used in non-conveyorized lines.

Dermal risk indicators of concern are presented in Table 3-31. This includes chemicals of potential concern based on MOE and/or HQ. Dermal exposure estimates are based on the assumption that both hands are routinely immersed in the bath, the worker does not wear gloves, and all non-conveyorized lines are operated by manual hoist.

Table 3-32 provides a summary of the potential health effects for the chemicals of concern listed in Tables 3-30 and 3-31. It should be noted that Tables 3-30 and 3-31 do not include chemicals for which toxicity data were unavailable. Table 3-33 lists chemicals where inhalation or dermal exposure is expected to occur, but appropriate toxicity values are not available. (Table 3-25 provides qualitative structure-activity information pertaining to chemical toxicity for those chemicals without available measured toxicity data.)

Table 3-30. Summary of Human Health Risks From Occupational Inhalation Exposure for Selected Chemicals

Chemical of Concern	Human Health Risk Indicator [a]			
	HASL (NC)	Nickel/Gold (NC)	Nickel/Palladium/Gold (NC)	OSP (NC)
Alkyldiol	NA	line operator	line operator	NA
Ethylene glycol	MOE (3, 9) 550, line operator LOAEL	NA	NA	MOE (3, 9) 370, line operator LOAEL
Hydrochloric acid	NA	HQ (1, 2, 3) 29, line operator	HQ (2, 12) 41, line operator	NA
Hydrogen peroxide	NA	MOE (9) 940, line operator LOAEL	MOE (9) 730, line operator LOAEL	NA
Inorganic metallic salt A	NA	cancer risk $< 1 \times 10^{-6}$, line operator	NA	NA
Nickel sulfate	NA	HQ (4) 23, line operator	HQ (4) 50, line operator	NA
Phosphoric acid	NA	HQ (3) 2.7, line operator	HQ (3) 3.5, line operator	NA
Propionic acid	NA	NA	MOE (5) 31, line operator LOAEL	NA

[a] This table includes results for chemicals and pathways with an MOE less than 1,000 if based on a LOAEL (or less than 100 if based on a NOAEL), an HQ greater than one, or cancer risk. It does not include chemicals for which toxicity data were unavailable. Specific results are not presented for confidential ingredients in order to protect proprietary ingredient identity.

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┌─────────────────────┐
│ A        (B)        │
│ C,D                 │
│ E                   │
└─────────────────────┘
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A: Type of risk indicator for which results are reported (HQ, MOE, or cancer risk).

B: Process bath(s) in which the chemical is used. These are only shown for non-proprietary chemicals. Numbers in parentheses indicate the process bath(s) in which the chemical is used:

(1) acid dip	(2) catalyst
(3) cleaner	(4) electroless nickel
(5) electroless palladium	(6) immersion gold
(7) immersion silver	(8) immersion tin
(9) microetch	(10) OSP
(11) predip	(12) preinitiator

C: Value calculated for risk indicator (cancer risk, HQ, or MOE).

D: Type of worker for which risk results are presented (line operator or laboratory technician).

E: Type of toxicity data used for MOE: NOAEL, LOAEL, or data from human exposures, which do not provide a range of exposures but identify levels that have adverse effects on humans.

NA: Not applicable.

Table 3-31. Summary of Human Health Risks Results From Occupational Dermal Exposure for Selected Chemicals

Chemical of Concern [a]	Human Health Risk Indicator [a,b]						
	HASL (NC)	HASL (C)	Nickel/Gold (NC)	Nickel/ Palladium/Gold (NC)	OSP (NC)	OSP (C)	Immersion Tin (NC)
Ammonia compound A	NA	NA	NA	line operator	NA	NA	NA
Ammonium chloride	NA	NA	HQ (6) 2.3, line operator	NA	NA	NA	NA
Ammonium hydroxide	NA	NA	HQ (6) 2.5, line operator	HQ (6) 3.5, line operator	NA	NA	NA
Copper ion	NA	NA	NA	NA	MOE (10) 0.68, line operator 10, lab tech LOAEL	MOE (10) 14, line operator 48, lab tech LOAEL	NA
Copper salt C	NA	NA	NA	NA	line operator	NA	NA
Copper sulfate pentahydrate	MOE (9) 2.7, line operator 190, lab tech LOAEL	MOE (9) 64, line operator 860, lab tech LOAEL	MOE (9) 0.77, line operator 12, lab tech LOAEL	MOE (9) 0.92, line operator 37, lab tech LOAEL	MOE (9) 3.0, line operator 46, lab tech LOAEL	MOE (9) 59, line operator 210, lab tech LOAEL	NA
Hydrogen peroxide	NA	NA	MOE (9) 430, line operator LOAEL	MOE (9) 510, line operator LOAEL	NA	NA	NA
Inorganic metallic salt B	NA	NA	line operator, lab tech	line operator, lab tech	NA	NA	NA
Nickel sulfate	NA	NA	HQ (4) 140, line operator 9.2, lab tech	HQ (4) 190, line operator 4.6, lab tech	NA	NA	NA
Urea compound C	NA	NA	NA	NA	NA	NA	line operator

[a] This table includes results for chemicals and pathways with an MOE less than 1,000 if based on LOAELs (or less than 100 based on NOAELs), an HQ greater than one, or cancer risk above 1x10^{-6}. It does not include chemicals for which toxicity data were unavailable. Specific results are not presented for confidential ingredients in order to protect proprietary ingredient identity.

How to read this table:

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┌──────────────┐
│ A    (B)     │
│ C,D          │
│ E            │
└──────────────┘
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A: Type of risk indicator for which results are reported (HQ, MOE, or cancer risk).

B: Process bath(s) in which the chemical is used. Numbers in parentheses indicate the process bath(s) in which the chemical is used:

(1) acid dip	(2) catalyst
(3) cleaner	(4) electroless nickel
(5) electroless palladium	(6) immersion gold
(7) immersion silver	(8) immersion tin
(9) microetch	(10) OSP
(11) predip	(12) preinitiator

C: Value calculated for risk indicator (cancer risk, HQ, or MOE).

D: Type of worker for which risk results are presented (line operator or laboratory technician).

E: Type of toxicity data used for MOE: NOAEL, LOAEL, or data from human exposures, which do not provide a range of exposures but identify levels that have adverse effects on humans.

NA: Not applicable.

For inhalation exposure to workers, the following chemicals result in an HQ greater than one or an MOE below the concern levels:

C   ethylene glycol in non-conveyorized HASL;
C   alkyldiol, hydrochloric acid, hydrogen peroxide, nickel sulfate, and phosphoric acid in non-conveyorized nickel/gold;
C   alkyldiol, hydrochloric acid, hydrogen peroxide, nickel sulfate, phosphoric acid, and propionic acid in non-conveyorized nickel/palladium/gold; and
C   ethylene glycol in non-conveyorized OSP.

Chemicals with HQs from dermal exposure greater than one, NOAEL-based MOEs lower than 100, or LOAEL-based MOEs lower than 1,000, include:

C   copper sulfate pentahydrate in non-conveyorized and conveyorized HASL;
C   ammonium chloride, ammonium hydroxide, copper sulfate pentahydrate, hydrogen peroxide, inorganic metallic salt B, and nickel sulfate in non-conveyorized nickel/gold;
C   ammonia compound A, ammonium hydroxide, copper sulfate pentahydrate, hydrogen peroxide, inorganic metallic salt B, and nickel sulfate in non-conveyorized nickel/palladium/gold;
C   copper ion, copper salt C, and copper sulfate pentahydrate in non-conveyorized OSP;
C   copper ion and copper sulfate pentahydrate in conveyorized OSP; and
C   urea compound C in non-conveyorized immersion tin.

Table 3-32. Summary of Potential Human Health Effects for Chemicals of Concern

Chemical of Concern	Potential Health Effects
Ammonia compound A, Ammonium chloride, and Ammonium hydroxide	Contact with ammonium chloride solution or fumes irritate the eyes. Large doses of ammonium chloride may cause nausea, vomiting, thirst, headache, hyperventilation, drowsiness, and altered blood chemistry. Ammonia fumes are extremely irritating to skin, eyes, and respiratory passages. The severity of effects depends on the amount of dose and duration of exposure.
Alkyldiol	Can affect the respiratory system if inhaled, and kidneys if absorbed into the body.
Copper ion, Copper sulfate pentahydrate, and Copper salt C	Long-term exposure to high levels of copper may cause liver damage. Copper is not known to cause cancer. The seriousness of the effects of copper can be expected to increase with both level and length of exposure.
Ethylene glycol	In humans, low levels of vapors produce throat and upper respiratory irritation. When ethylene glycol breaks down in the body, it forms chemicals that crystallize and can collect in the body, which prevent kidneys from working. The seriousness of the effects can be expected to increase with both level and length of exposure.
Hydrochloric acid	Hydrochloric acid in the air can be corrosive to the skin, eyes, nose, mucous membranes, respiratory tract, and gastrointestinal tract.
Hydrogen peroxide	Hydrogen peroxide in the air can irritate the skin, nose, and eyes. Ingestion can damage the liver, kidneys, and gastrointestinal tract.
Inorganic metallic salt A	Exposure can cause flu-like symptoms, weakness and coughing, and has been linked to lung cancer and kidney disease.
Inorganic metallic salt B	Exposure to this material can damage the nervous system, kidneys, and immune system.
Nickel sulfate	Skin effects are the most common effects in people who are sensitive to nickel. Workers who breath very large amounts of nickel compounds have developed lung and nasal sinus cancers.
Phosphoric acid	Inhaling phosphoric acid can damage the respiratory tract.
Propionic acid	No data were located for health effects of propionic acid exposure in humans, although some respiratory effects were seen in laboratory mice.
Urea compound C	Dermal exposure to urea compound C has resulted in allergic contact dermatitis in workers, and exposure has caused weight loss in mice.

Table 3-33. Data Gaps for Chronic Non-Cancer Health Effects for Workers

Chemical	Inhalation [a] or Dermal [b] Exposure Potential	SAT Rank (if available)
HASL		
1,4-Butenediol	Inhalation and Dermal	Low-moderate
Alkylaryl sulfonate	Inhalation	Low
Arylphenol	Inhalation	Moderate
Fluoboric acid	Dermal	
Hydrochloric acid	Dermal	
Sodium hydroxide	Dermal	
Sulfuric acid	Dermal	
Tin	Dermal	
Nickel/Gold		
Aliphatic acid A	Inhalation	
Aliphatic acid B	Inhalation	Moderate
Aliphatic acid E	Inhalation and Dermal	
Aliphatic dicarboxylic acid A	Inhalation	Low-moderate
Aliphatic dicarboxylic acid C	Inhalation	
Alkylamino acid B	Dermal	
Ammonia compound B	Inhalation	Moderate-high
Hydrochloric acid	Dermal	
Malic acid	Inhalation	Low-moderate
Palladium chloride	Dermal	
Potassium compound	Inhalation and Dermal	Low
Sodium hydroxide	Dermal	
Sodium hypophosphite	Inhalation	Low-moderate
Sulfuric acid	Dermal	
Urea compound B	Inhalation and Dermal	
Nickel/Palladium/Gold		
Aliphatic acid B	Inhalation	Moderate
Aliphatic acid E	Inhalation and Dermal	
Aliphatic dicarboxylic acid A	Inhalation	Low-moderate
Aliphatic dicarboxylic acid C	Inhalation	
Ammonia compound B	Inhalation	Moderate-high
Hydrochloric acid	Dermal	
Malic acid	Inhalation	Low-moderate
Palladium salt	Dermal	
Potassium compound	Inhalation and Dermal	Low
Sodium hydroxide	Dermal	

Chemical	Inhalation [a] or Dermal [b] Exposure Potential	SAT Rank (if available)
Sodium hypophosphite monohydrate	Inhalation	Low-moderate
Sulfuric acid	Dermal	
Urea compound B	Inhalation and Dermal	
OSP		
Acetic acid	Inhalation	
Alkylaryl imidazole	Dermal	Low-moderate
Aromatic imidazole product	Dermal	
Arylphenol	Inhalation	Moderate
Hydrochloric acid	Dermal	
Sodium hydroxide	Dermal	
Sulfuric acid	Dermal	
Immersion Silver		
1,4-Butenediol	Dermal	Low-moderate
Nitrogen acid	Dermal	
Sodium hydroxide	Dermal	
Sulfuric acid	Dermal	
Immersion Tin		
Alkylaryl sulfonate	Inhalation	Low
Fluoboric acid	Dermal	
Hydrochloric acid	Dermal	
Methane sulfonic acid	Dermal	
Sulfuric acid	Dermal	
Thiourea	Dermal	
Urea compound C	Inhalation	

[a] Applies only to the non-conveyorized process configuration.
[b] Applies to either process configuration.

Lead

Risk results for workers from lead in the HASL process are presented in Section 3.4.6.

Ambient (Outdoor) Environment

Potential risks are evaluated from exposure to chemicals released to outdoor air from a PWB facility. Inhalation is the only exposure route to be quantified for people living nearby a model PWB facility.

Cancer Risk. As with the occupational setting, the nickel/gold process is the only process for which cancer risk to humans in the ambient (outdoor) environment has been estimated. These results for the non-conveyorized nickel/gold process, assuming that emissions are vented to the outside, are an upper bound excess[20] individual lifetime cancer risk for nearby residents of 2×10^{-11}. Inorganic metallic salt A is a human carcinogen.[21] These estimates indicate low concern and are interpreted to mean that, over a lifetime, an individual resident is expected to have no more than one chance in 50 billion of developing cancer from exposure to inorganic metallic salt A from a nearby facility using the non-conveyorized process.

None of the other process alternatives use chemicals for which cancer slope factors were available, so no other cancer risks were estimated. Other identified chemicals in the surface finishing processes are suspected carcinogens, but do not have established slope factors. Lead and thiourea have been determined by IARC to be possible human carcinogens (IARC Group 2B); lead has also been classified by EPA as a probable human carcinogen (EPA Class B2). Lead is used in tin-lead solder in the HASL process. Thiourea is used in the immersion tin process. Urea compound B, a confidential ingredient in the nickel/gold and nickel/palladium/gold processes, is possibly carcinogenic to humans. Exposure for nearby residents from these chemicals has been estimated, but cancer potency and cancer risks are unknown. Additionally, strong inorganic and acid mists of sulfuric acid have been determined by IARC to be a human carcinogen (IARC Group 1). Sulfuric acid is used in diluted form in every surface finishing process in this evaluation. It is not expected, however, to be released to the environment as a strong acid mist.

Non-Cancer Risk. All HQs are less than one for ambient exposure to the general population, indicating low concern from the estimated air concentrations. An MOE was calculated for chemicals if an inhalation LOAEL or NOAEL was available and an RfC was not. All MOEs for ambient exposure are greater than 1,000 for all processes, indicating low concern.

These results suggest there is low risk to nearby residents, based on incomplete but best available data. Data limitations include the use of modeled air concentrations using data compiled for a model facility rather than site-specific, measured concentrations. For estimating ambient (outdoor) air concentrations, one key assumption is that no air pollution control technologies are used to remove airborne chemicals from facility air prior to venting it to the outside. Other data limitations are the lack of solid waste data to characterize exposure routes in addition to inhalation, and lack of toxicity data for many chemicals.

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[20] *Upper bound* refers to the method of determining a slope factor, where the upper bound value (generated from a certain probability statement) for the slope of the dose-response curve is used. *Excess* means the estimated cancer risk is in addition to the already-existing background risk of an individual contracting cancer from all other causes.

[21] A cancer classification of known human carcinogen has been assigned by either the EPA, IARC, and/or NTP. Further details about the carcinogen classification are not provided in order to protect the confidential chemical's identity.

Lead. Risk results for people living near a PWB facility from lead in the HASL process are presented below in Section 3.4.6.

3.4.6 Evaluation of Lead Risks from Tin-Lead Solder Used in the HASL Process

Although classified as a probable carcinogen by EPA, and known to cause other serious health effects from chronic exposure, EPA has not derived a cancer slope factor, an RfD, or an RfC for lead. Therefore, it is not possible to calculate a cancer risk, and the standard approach of calculating an HQ to assess non-cancer health risks is not used for lead. Instead, lead exposure is estimated using one of two exposure-biokinetic models, the Interim Adult Lead Methodology (U.S. EPA, 1996a) and the Integrated Exposure Uptake Biokinetic Model for Lead in Children (U.S. EPA, 1994). Both of these models relate estimated exposure levels to a lead concentration in blood, which can then be compared to blood-lead levels at which health effects are known to occur. These models are described further in Section 3.2.4 of the Exposure Assessment.

Table 3-34 presents federal (and other) regulations and guidelines for lead. This table also presents comparable lead exposure values for workers and the ambient environment potentially resulting from the lead in tin-lead solder used in the HASL process. For workers, the lowest federal target or action levels are from OSHA and ACGIH, at 30 µg/dL in blood. By comparison, the 5 to 12 µg/dL blood-lead levels from actual facility monitoring data for HASL line operators are below this level. These monitoring data are limited to one facility, however.

We also modeled worker blood-lead levels using EPA's Adult Lead Methodology. Estimated adult worker blood-lead levels (central estimate) from the model range from 2 to 63 µg/dL, depending on the worker's lead intake rate. This estimate is higher than the limited available monitoring data, with workers' measured blood-lead levels from 5 to 12 µg/dL. Estimated lead exposure using this model are very uncertain and could vary greatly depending on worker activities. The ALM model was run based on the assumption that a worker gets lead on his/her hands from handling solder, and then accidentally ingests some of that lead (e.g., by eating or smoking without thoroughly washing their hands). The amount of lead ingested this way is highly uncertain. Results from the model are based on a "conservative overestimate" from surface wipe samples in hand soldering operations of 0.03 mg/day (Monsalve, 1984) and on a range of soil ingestion rates of 10 to 50 mg/day for an adult in contact with soil (Stanek et al., 1997 and U.S. EPA 1997a), respectively.[22] (Ingestion data are not available specifically for a HASL worker handling solder.) However, these results do indicate that there may be risk from lead exposure via the ingestion route from poor hygiene practices.

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[22] 10 mg/day is an average estimate; 50 mg/day is a central tendency estimate.

Table 3-34. Risk Evaluation Summary for Lead

Federal Regulations and Guidelines for Lead			Lowest Federal Level	Comparable Lead Exposure Values	
Workplace					
Worker blood-lead target/action levels	OSHA, adults "who wish to bear children"	30 µg/100g	30 µg/dL	Occupational blood-lead monitoring data.	5 - 12 µg/dL
	OSHA, blood-lead level of concern	40 µg/dL		Modeled (ALM) blood-lead data for an adult worker.	2 - 63 µg/dL (depending on intake rate)
	OSHA, medical removal	50 µg/dL			
	ACGIH (ACGIH, 1998)	30 µg/dL			
	NIOSH, level to be maintained through air concentrations	60 µg/100 g			
Pregnant worker: fetal blood-lead target/action levels	OSHA	30 µg/100g	10 µg/dL	Modeled (ALM) fetal blood-lead level.	3 - 102 µg/dL (depending on maternal intake rate)
	CDC	10 µg/dL [a]			
Workplace air exposure limit	OSHA PEL (8 hr TWA)	50 µg/m³	50 µg/m³	Workplace air monitoring data (average of HASL process area monitoring data provided by one PWB manufacturer).	3 µg/m³
	NIOSH REL (NIOSH, 1994)	100 µg/m³			
	ACGIH TLV TWA (ACGIH, 1998)	50 µg/m³			
Ambient Environment					
Ambient air concentration	National Ambient Air Quality Standard, (U.S. EPA, 1987b)	1.5 µg/m³ (averaged over 3 mo.)	1.5 µg/m³	Ambient air concentrations near a PWB facility based on HASL workplace air monitoring data and air dispersion model.	0.00009 µg/m³
Blood-lead target/action levels for child	CDC	10 µg/m³	10 µg/m³	Not determined. The IEUBK model estimates blood-lead levels for children age 0 through 6 years. However, estimated ambient air concentration from a HASL process are 1,000 times lower than the default value for air in the model. IEUBK model results using default values range from 2.7 to 4.5 µg/dL.	
	OSHA	30 µg/100g			
	International: WHO blood lead level of concern (WHO, 1986)	20 µg/dL			

[a] CDC considers children to have an elevated level of lead if the amount of lead in the blood is at least 10 µg/dL. Medical evaluation and environmental remediation should be done for all children with blood levels > 20 µg/dL. Medical treatment may be necessary in children if the blood lead concentration is > 45 µg/dL (RTI, 1999).

NOTES:

ACGIH: American Conference of Governmental Industrial Hygienists, Inc.

CDC: Centers for Disease Control and Prevention.

EPA: U.S. Environmental Protection Agency.

NIOSH: National Institute for Occupational Safety and Health.

OSHA: Occupational Safety and Health Administration.

WHO: World Health Organization.

PEL: Permissible Exposure Limit.

REL: Recommended Exposure Level.

TWA: Time-weighted average.

TLV: Threshold limit value.

ALM: Adult Lead Methodology.

IEUBK: Integrated Exposure Uptake Biokinetic Model for Lead in Children.

About units: µg/dL = micrograms of elemental lead per deciliter (100 mL) of blood; 100 g blood is approximately equal to 100 mL or 1 dL.

In addition to an adult worker, we used the ALM to model potential fetal blood-lead levels, assuming a pregnant HASL line operator is exposed to lead through incidental ingestion. Estimated 95th percentile fetal blood-lead levels of from 3.2 to 100 µg/dL can be compared to the guidance level from CDC and EPA of 10 µg/dL for children.[23] Again, these estimates are based on uncertain ingestion rates.

Estimated workplace and ambient air concentration of lead also can be compared directly to air regulations and guidelines for airborne lead from federal agencies (e.g., U.S. EPA, OSHA) and the World Health Organization (WHO). For the workplace, an average of air monitoring data from one PWB manufacturer[24] of 3 µg/m^3 can be compared to the lowest federal regulatory level of 50 µg/m^3 (an OSHA, 8-hour, time-weighted average permissible exposure limit). For ambient air near a facility, an estimated air concentration of 0.0001 µg/m^3 is well below the EPA air regulation of 1.5 µg/m. (Ambient air modeling from a PWB facility is described further in Section 3.2.3 of the Exposure Assessment.) It should be noted that these air monitoring data are also limited to only one PWB manufacturer, and may vary from facility to facility.

The recommended approach for evaluating lead exposure to nearby residents is to apply the IEUBK model to estimate blood-lead levels in children who may be exposed. (This is discussed further in Section 3.2.4.) The default air concentration set in the model, based on average 1990 U.S. urban air levels, is 1,000 times higher than the ambient air concentration estimated from a HASL process. The IEUBK model could not discern any difference in children's blood-lead levels based on such a small incremental increase in background air concentrations. Based on these results, risks from lead exposure to nearby residents is expected to be below concern levels.

3.4.7   Results of Calculating Ecological (Aquatic) Risk Indicators

We calculated ecological risk indicators (RI_{ECO}) for aquatic organisms as a unitless ratio:

$$RI_{ECO} = C_{SW} / CC$$

where,
C_{SW} =   estimated surface water concentration following treatment in a POTW (mg/l)
CC   =   concern concentration (mg/l)

The method for estimating surface water concentrations is described in Section 3.2.3 of the Exposure Assessment. Exposure concentrations below the CC are assumed to present low risk to aquatic species. An ecological risk indicator greater than one indicates that the estimated

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[23] CDC considers children to have an elevated level of lead if the amount of lead in the blood is at least 10 µg/dL. Medical evaluation and environmental remediation should be done for all children with blood-lead levels $20 µg/dL. Medical treatment may be necessary in children if the blood-lead concentration is > 45 µg/dL (RTI, 1999).

[24] Results from both personal monitoring for HASL line operators and air samples from the HASL process area were averaged.

chemical concentration exceeds the concentration of concern for the aquatic environment based on chemical toxicity to aquatic organisms. The level of concern increases as the ratio of exposure concentration to CC increases. the derivation of CCs is described in Section 3.3.3 of the Human Health and Ecological Hazards Summary and in Appendix H.

The results for non-metal surface finishing chemicals are summarized in Table 3-35. Estimated surface water concentrations of several non-metals exceed the CC, as follows:

C   alkylaryl sulfonate, 1,4-butenediol, hydrogen peroxide, and potassium peroxymonosulfate in the non-conveyorized HASL process;
C   alkylaryl sulfonate, hydrogen peroxide, and potassium peroxymonosulfate in the conveyorized HASL process;
C   alkylaryl imidazole in non-conveyorized and conveyorized configurations of the OSP process;
C   hydrogen peroxide in the conveyorized immersion silver process; and
C   potassium peroxymonosulfate in the non-conveyorized the immersion tin process (the estimated surface water concentration per thiourea is equal to the CC).

Table 3-35. Summary of Aquatic Risk Indicators for Non-Metal Chemicals of Concern

Chemical	CC (mg/L)	Aquatic Risk Indicator (RI$_{ECO}$)					
		HASL (NC)	HASL (C)	OSP (NC)	OSP (C)	Imm. Silver (C)	Imm. Tin (NC)
1,4-Butenediol	0.008	1.3	NA	NA	NA	NA	NA
Alkylaryl imidazole	0.001 - 0.005	NA	NA	6.6 - 33	3.6 - 18	NA	NA
Alkylaryl sulfonate	0.001 - 0.005	1 - 5	0.7 - 3.5	NA	NA	NA	NA
Hydrogen peroxide	0.02	2.0	1.5	NA	NA	1.3	NA
Potassium peroxymonosulfate	0.01	8.2	6.1	NA	NA	NA	3.6
Thiourea	0.03	NA	NA	NA	NA	NA	1.0 [a]

[a] Estimated surface water concentration is equal to the CC; this is not counted as an exceedance.
NA: Not applicable; estimated surface water concentration is less than CC or the chemical is not an ingredient of that process configuration.
NC: Non-conveyorized.
C: Conveyorized.

It is assumed that on-site treatment is targeted to remove metals so that permitted concentrations are not exceeded. If on-site treatment is not used to remove metals, high aquatic risk indicators are possible. The ratio of estimated surface water concentration to CC for metals is presented in Table 3-36. These data are presented to highlight the importance of on-site treatment for toxic metals; because on-site treatment is expected to be performed to meet water discharge permit requirements, these results are not used in comparing potential aquatic risks among surface finishing alternatives.

Table 3-36. Summary of Aquatic Risk Indicators for Metals Assuming No On-Site Treatment

Chemical	CC (mg/L)	Aquatic Risk Indicator (RI_{ECO})					
		HASL (NC)	HASL (C)	Nickel/ Gold	Nickel/ Palladium/ Gold	OSP (NC)	OSP (C)
Copper ion	0.001	NA	NA	NA	NA	46	25
Copper sulfate pentahydrate	0.01	5.1	3.8	NA	NA	6.3	5.1
Nickel sulfate	0.01	NA	NA	5.1	5.5	NA	NA
Potassium gold cyanide	0.003	NA	NA	1.5	NA	NA	NA

NA: Not applicable; estimated surface water concentration is less than CC or the chemical is not an ingredient of that process configuration.
NC: Non-conveyorized.
C: Conveyorized.

3.4.8   Uncertainties

An important component of any risk characterization is the identification and discussion of uncertainties. There are uncertainties involved in the measurement and selection of hazard data, and in the data, models, and scenarios used in the Exposure Assessment. Any use of the risk characterization should include consideration of these uncertainties.

Uncertainties in the Exposure Assessment include the following:

C   accuracy of the description of exposure setting: how well the model facility used in the assessment characterizes an actual facility; the likelihood of exposure pathways actually occurring (scenario uncertainty);

C   missing data and limitations of workplace practices data: this includes possible effects of any chemicals that may not have been included (e.g., minor ingredients in the formulations); possible effects of side reactions in the baths which were not considered; and questionnaire data with limited facility responses;

C   estimating exposure levels from averaged data and modeling in the absence of measured, site-specific data;

C   data limitations in the Source Release Assessment: releases to land could not be characterized quantitatively;

C   chemical fate and transport model applicability and assumptions: how well the models and assumptions represent the situation being assessed and the extent to which the models have been validated or verified (model uncertainty);

C   parameter value uncertainty, including measurement error, sampling (or survey) error, parameter variability, and professional judgement; and

C   uncertainties in estimating exposure to lead, especially with assumptions made about hand-to-mouth lead intake rates for workers.

Key assumptions made in the Exposure Assessment are discussed in Section 3.4.1.

Uncertainties in the human health hazard data (as typically encountered in a hazard assessment) include the following:

C   using dose-response data from high dose studies to predict effects that may occur at low levels;
C   using data from short-term studies to predict the effects of long-term exposures;
C   using dose-response data from laboratory animals to predict effects in humans;
C   using data from homogeneous populations of laboratory animals or healthy human populations to predict the effects on the general human population, with a wide range of sensitivities (uncertainty due to natural variations in human populations);
C   using LOAELs and NOAELs in the absence of peer-reviewed RfDs and RfCs;
C   possible increased or decreased toxicity resulting from chemical interactions;
C   assuming a linear dose-response relationship for cancer risk (in this case for inorganic metallic salt A);
C   effects of chemical mixtures not included in toxicity testing (effects may be independent, additive, synergistic, or antagonistic); and
C   possible effects of substances not evaluated because of a lack of chronic/subchronic toxicity data.

Uncertainties in the ecological hazards data and ecological risk characterization, which attempt to evaluate potential ecotoxicity impacts to aquatic organisms from long-term (chronic) exposure in a receiving stream, include the following:

C   use of laboratory toxicity data to evaluate the effects of exposure in a stream;
C   use of estimated toxicity data in the absence of measured data;
C   use of data from acute exposure to evaluate the effect of chronic exposures;
C   variation in species sensitivity; and
C   uncertainties in estimating surface water concentrations from the drag-out model and predicted POTW treatment efficiencies; also, surface water concentrations are based on estimated releases to a modeled stream flow for the electronics industrial sector.

Another source of uncertainty comes from use of structure-activity relationships (SARs) for estimating human health hazards in the absence of experimental toxicity data. Specifically, this was done for: aliphatic acid B, aliphatic dicarboxylic acid A, alkylalkyne diol, alkylamino acid A, alkylaryl imidazole, alkylaryl sulfonate, alkylimine dialkanol, amino acid salt, ammonia compound B, aryl phenol, bismuth compound, 1,4-butenediol, citric acid, ethoxylated alkylphenol, fatty amine, hydroxyaryl acid, hydroxyaryl sulfonate, maleic acid, malic acid, potassium compound, potassium peroxymonosulfate, quaternary alkylammonium chlorides, sodium benzene sulfonate, sodium hypophosphite, sodium hypophosphite monohydrate, substituted amine hydrochloride, and transition metal salt.

Uncertainties in assessing risk from dermal exposure come from the use of toxicological potency factors from studies with a different route of exposure than the one under evaluation (i.e., using oral toxicity measures to estimate dermal risk). This was done for chemicals with oral RfDs and chemicals with oral NOAELs or LOAELs (as noted in Tables 3-25 and 3-26).

Uncertainties in dermal risk estimates also stem from the use of default values for missing gastrointestinal absorption data. Specifically, this was done for: aliphatic acid E, aliphatic dicarboxylic acid C, alkylamino acid B, alkylpolyol, amino carboxylic acid, fluoboric acid, gum, hydrogen peroxide, hydroxy carboxylic acid, nitrogen acid, potassium gold cyanide, propionic acid, stannous methane sulfonic acid, and sulfuric acid, and urea compound C.

Finally, the risk characterization does not address the potential adverse health effects associated with acute exposure to peak levels of chemicals. This type of exposure is especially important when evaluating developmental risks associated with exposure.

3.4.9   Conclusions

This risk characterization uses a health-hazard based framework and a model facility approach to compare the potential health risks of one surface finishing process technology to the potential risks associated with switching to an alternative technology. As much as possible, reasonable and consistent assumptions are used across alternatives. Data to characterize the model facility and exposure patterns for each process alternative were aggregated from a number of sources, including PWB shops in the U.S., supplier data, and input from PWB manufacturers at project meetings. Thus, the model facility is not entirely representative of any one facility, and actual risk could vary substantially, depending on site-specific operating conditions and other factors.

When using the results of this risk characterization to compare potential health effects among alternatives, it is important to remember that this is a screening level rather than a comprehensive risk characterization, both because of the predefined scope of the assessment and because of exposure and hazard data limitations. It should also be noted that this approach does not result in any absolute estimates or measurements of risk, and even for comparative purposes, there are several important uncertainties associated with this assessment.

Another significant source of uncertainty is the limited data available for dermal toxicity and the use of oral to dermal extrapolation when dermal toxicity data were unavailable. There is high uncertainty in using oral data for dermal exposure and in estimating dermal absorption rates, which could result in either over- or under-estimates of exposure and risk.

A third significant source of uncertainty is from the use of SARs to estimate toxicity in the absence of measured toxicity data, and the lack of peer-reviewed toxicity data for many surface finishing chemicals. Other uncertainties associated with the toxicity data include the possible effects of chemical interactions on health risks, and extrapolation of animal data to estimate human health risks from exposure to inorganic metallic salt A and other PWB chemicals.

Another major source of uncertainty in estimating exposure is the reliance on modeled data (i.e., modeled air concentrations) to estimate worker and ambient exposure. It should also be noted that there is no comparative evaluation of the severity of effects for which HQs and MOEs are reported.

The Exposure Assessment for this risk characterization, whenever possible, used a combination of central tendency and high-end assumptions, as would be used for an overall high-end exposure estimate. Some values used in the exposure calculations, however, are better characterized as "what-if," especially pertaining to exposure frequency, bath concentrations, use of gloves, and process area ventilation rates for a model facility. Because some part of the exposure assessment for both inhalation and dermal exposures qualifies as a "what-if" descriptor, the entire assessment should be considered "what-if."

Occupational Exposures and Risks

Health risks to workers were estimated for inhalation exposure to vapors and aerosols from surface finishing baths and for dermal exposure to surface finishing bath chemicals. Inhalation exposure estimates are based on the assumptions that emissions to indoor air from conveyorized lines are negligible, that the air in the process room is completely mixed and chemical concentrations are constant over time, and that no vapor control devices (e.g., bath covers) are used in non-conveyorized lines. Dermal exposure estimates are based on the assumption that workers do not wear gloves and that all non-conveyorized lines are operated by manual hoist. Dermal exposure to line operators on non-conveyorized lines is estimated for routine line operation and maintenance (e.g., bath replacement, filter replacement), and on conveyorized lines for bath maintenance activities alone.

Based on the number of chemicals with risk results above concern levels, some alternatives to the non-conveyorized HASL process appear to pose lower occupational risks (i.e., conveyorized immersion silver, conveyorized and non-conveyorized immersion tin, and conveyorized HASL), some may pose similar levels of risk (i.e., conveyorized and non-conveyorized OSP), and some may pose higher risk (i.e., non-conveyorized nickel/gold and nickel/palladium/gold). There are occupational inhalation risk concerns for chemicals in the non-conveyorized HASL, nickel/gold, nickel/palladium/gold, and OSP processes. There are also occupational risk concerns for dermal contact with chemicals in the non-conveyorized HASL, nickel/gold, nickel/palladium/gold, OSP, and immersion tin processes, and the conveyorized HASL and OSP processes.

Cancer Risk. The non-conveyorized nickel/gold process contains the only chemical for which an occupational cancer risk has been estimated (inorganic metallic salt A). The line operator inhalation exposure estimate for inorganic metallic salt A results in an estimated upper bound excess individual life time cancer risk of 2×10^{-7} (one in five million) based on high end exposure. Cancer risks less than 1×10^{-6} (one in one million) are generally considered to be of low concern. Risks to other types of workers[25] were assumed to be proportional to the average amount of time spent in the process area, which ranged from 12 to 69 percent of the risk for a line operator.

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[25] These include laboratory technicians, maintenance workers, supervisors, and wastewater treatment operators. Other types of workers may be present for shorter or longer times.

Other identified chemicals in the surface finishing processes are suspected or known carcinogens. Lead and thiourea have been determined by IARC to be possible human carcinogens (IARC Group 2B); lead has also been classified by EPA as a probable human carcinogen (EPA Class B2). Lead is used in tin-lead solder in the HASL process. Thiourea is used in the immersion tin process. Urea compound B, a confidential ingredient in the nickel/gold and nickel/palladium/gold processes, is possibly carcinogenic to humans. Exposure for workers from these chemicals has been estimated, but cancer potency and cancer risks are unknown. Additionally, strong inorganic and acid mists of sulfuric acid have been determined by IARC to be a human carcinogen (IARC Group 1). Sulfuric acid is used in diluted form in every surface finishing process in this evaluation. It is not expected, however, to be released to the air as a strong acid mist. There are potential cancer risks to workers from these chemicals, but because there are no slope factors, the risks cannot be quantified.

Non-Cancer Risk. For non-cancer risk, HQs greater than one, NOAEL-based MOEs lower than 100, or LOAEL-based MOEs lower than 1,000 were estimated for occupational exposures to chemicals in the non-conveyorized and conveyorized HASL processes, non-conveyorized nickel/gold process, non-conveyorized nickel/palladium/gold process, non-conveyorized and conveyorized OSP processes, and the non-conveyorized immersion tin process.

Based on calculated occupational exposure levels, there may be adverse health effects to workers exposed to chemicals with an HQ exceeding 1.0 or an MOE less than 100 or 1,000. However, it should be emphasized that these conclusions are based on screening level estimates. These numbers are used here for relative risk comparisons between processes, and should not be used as absolute indicators for actual health risks to surface finishing line workers.

Lead. Worker blood-lead levels measured at one PWB manufacturing facility were below any federal regulation or guideline for workplace exposure. Modeling data, however, indicate that blood-lead levels could exceed recommended levels for an adult and fetus, given high incidental ingestion rates of lead from handling solder. These results are highly uncertain; ingestion rates are based on surface wipe samples from hand soldering operations and on incidental soil ingestion rates for adults in contact with soil. However, this indicates the need for good personal hygiene for HASL line operators, especially wearing gloves and washing hands to prevent accidental hand-to-mouth ingestion of lead.

Public Health Risks

Potential public health risk was estimated for inhalation exposure for the general public living near a PWB facility. Public exposure estimates are based on the assumption that emissions from both conveyorized and non-conveyorized process configurations are vented to the outside. The risk indicators for ambient exposures to humans, although limited to airborne releases, indicate low concern for nearby residents. The upper bound excess individual cancer risk for nearby residents from inorganic metallic salt A in the non-conveyorized nickel/gold process was estimated to be from approaching zero to 2×10^{-11} (one in 50 billion). This chemical has been

classified as a human carcinogen.[26] All hazard quotients are less than one for ambient exposure to the general population, and all MOEs for ambient exposure are greater than 1,000 for all processes, indicating low concern from the estimated air concentrations for chronic non-cancer effects.

Estimated ambient air concentrations of lead from a HASL process are well below EPA air regulatory limits for lead, and risks to the nearby population from airborne lead are expected to be below concern levels.

Ecological Risks

We calculated ecological risk indicators (RI_{ECO}) for non-metal surface finishing chemicals that may be released to surface water. Risk indicators for metals are not used for comparing alternatives because it is assumed that on-site treatment is targeted to remove metals so that permitted concentrations are not exceeded. Estimated surface water concentrations for non-metals exceeded the CC in the following processes: four in the non-conveyorized HASL process, three in the conveyorized HASL process, one in the non-conveyorized OSP process, one in the conveyorized OSP process, one in the conveyorized immersion silver process, and one in the non-conveyorized immersion tin process.

Overall Risk Screening and Comparison Summary

Table 3-37 presents an overall comparison of potential human health and ecological risks for the baseline (non-conveyorized HASL) and the alternative process configurations.

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[26] A cancer classification of known human carcinogen has been assigned by either the EPA, IARC, and/or NTP. Further details about the carcinogen classification are not provided in order to protect the confidential chemical identity.

Table 3-37. Overall Comparison of Potential Human Health and Ecological Risks for the Non-Conveyorized HASL and Alternative Processes

Process	Number of Chemicals					
	Potential Carcinogen [a]	Inhalation Concern [b]	Dermal Concern [c]	Inhalation Data Gaps [d]	Dermal Data Gaps [e]	Aquatic Concern [f]
HASL (NC) (Baseline)	2	1	1+ lead	3	6	4
HASL (C)	2	0	1+ lead	0	6	3
Nickel/Gold (NC)	3	5	6	10	8	0
Nickel/Palladium/Gold (NC)	1	6	6	9	7	0
OSP (NC)	1	1	3	2	5	1
OSP (C)	1	0	2	0	5	1
Immersion Silver (C)	1	0	0	0	4	1
Immersion Tin (NC)	1	0	1	2	5	1
Immersion Tin (C)	1	0	0	0	5	0

[a] The number of chemicals with an EPA cancer WOE of A, B1, or B2, or an IARC WOE of 1, 2A, or 2B (see Table 3-21).

[b] The number of chemicals for which the HQ for worker inhalation exceeds 1, the NOAEL-based MOE is less than 100, or the LOAEL-based MOE is less than 1,000. See Table 3-30 for detailed results.

[c] The number of chemicals for which the HQ for dermal contact by workers exceeds 1, the NOAEL-based MOE is less than 100, or the LOAEL-based MOE is less than 1,000. See Table 3-30 for detailed results.

[d] The number of chemicals for which worker inhalation exposure is possible, but appropriate toxicity data are not available for calculating a risk indicator (see Table 3-33).

[e] The number of chemicals for which worker dermal contact is possible but appropriate toxicity data are not available for calculating a risk indicator (see Table 3-33).

[f] The number of chemicals for which the ecological risk indicators exceeds the concern level (i.e., $RI_{eco} > 1.0$). See Table 3-35 for detailed results.

3.5   PROCESS SAFETY ASSESSMENT

Process safety is a concern and responsibility of employers and employees alike. Each company has the obligation to provide its employees with a safe and healthy work environment, while each employee is responsible for his/her own safe personal work habits. In the surface finishing process of PWB manufacturing, hazards may be either chemical or process hazards. Chemicals used in the surface finishing process can be hazardous to worker health and, therefore, must be handled and stored properly, using appropriate personal protective equipment and safe operating practices. Automated equipment can be hazardous to employees if safe procedures for cleaning, maintaining, and operating the equipment are not established and regularly performed. These hazards can result in serious injury and health problems to employees, and potential damage to equipment.

The U.S. Department of Labor and the Occupational Safety and Health Administration (OSHA) have established safety standards and regulations to assist employers in creating a safe working environment and protecting workers from potential workplace hazards. In addition, individual states may also have safety standards regulating chemical and physical workplace hazards for many industries. Federal safety standards and regulations affecting the PWB industry can be found in the Code of Federal Regulations (CFR) Title 29, Part 1910, and are available by contacting your local OSHA field office. State and local regulations are available from the appropriate state office.

An effective process safety program identifies potential workplace hazards and, if possible, seeks to eliminate or at least reduce their potential for harm. Some companies have successfully integrated the process safety program into their ISO 14000 certification plan, often establishing process safety practices that go beyond OSHA regulations. This section of the CTSA presents chemical and process safety concerns associated with the surface finishing baseline technology and substitutes, as well as OSHA requirements to mitigate these concerns.

3.5.1   Chemical Safety Concerns

As part of its mission, OSHA's Hazard Communication Standard (29 CFR 1910.1200) requires that chemical containers be labeled properly with chemical name and warning information [.1200(f)], that employees be trained in chemical handling and safety procedures [.1200(h)], and that a MSDS be created and made available to employees for every chemical or chemical formulation used in the workplace [.1200(g)]. Each MSDS must be in English and include information regarding the specific chemical identity and common name of the hazardous chemical ingredients. In addition, information must be provided on the physical and chemical characteristics of the hazardous chemical(s), known acute and chronic health effects and related health information, exposure limits, whether the chemical is a carcinogen, emergency and first-aid procedures, and the identification of the organization preparing the data sheet. Copies of MSDSs for all of the chemicals/chemical formulations used must be kept and made available to workers who may come into contact with the process chemicals during their regular work shift.

In order to evaluate the chemical safety concerns of the various surface finishing processes, MSDSs for 37 chemical products comprising six surface finishing technology categories were collected and reviewed for potential hazards to worker safety. MSDSs were not received for five confidential chemical products. Chemical safety data for pure chemical compounds not sold as products were obtained from the Merck Index (Budavari, 1989).

Evaluating the chemical safety concerns specific to the HASL process baths was not possible because there are no suppliers of microetch or cleaner baths made specifically for the HASL process. Manufacturers will typically use the same microetch and cleaner formulation that is used as part of another process line (e.g., the microetch and cleaner used in the making holes conductive line). The chemical safety hazards for the HASL baths are similar to those reported by the other processes for the same bath type. Therefore, the worse case bath from another process was selected and reported for the HASL process to indicate the maximum safety hazard which could be associated with the HASL process bath. Actual safety hazards for the bath will depend greatly on the bath chemistry selected, and so may be less than the stated values.

Alternative processes with more than one product line submitted for evaluation were treated in a similar manner to the HASL process. For each bath category, the actual bath which posed the greatest hazard for each chemical hazard category was listed. For example, the microetch bath which posed the greatest hazard, out of the two microetch baths submitted for OSP, was listed for the OSP process

The results of that review are summarized and discussed in the sections below. General information on OSHA storage and handling requirements for chemicals is located in Section 3.5.3. For a more detailed description of OSHA storage and handling requirements for surface finishing chemical products, contact your area OSHA field office or state technical assistance program.

Flammable, Combustible, and Explosive Surface Finishing Chemical Products

Table 3-38 presents a breakdown of surface finishing chemical products that, when in concentrated form, are flammable, combustible, explosive, or pose a fire hazard. The following lists OSHA definitions for chemicals in these categories, and discusses the data presented in the table.

**Table 3-38. Flammable, Combustible, Explosive, and Fire Hazard Possibilities
for Surface Finishing Processes**

Surface Finishing Process	Bath Type	Hazardous Property [a, b]			
		Flammable	Combustible	Explosive	Fire Hazard
HASL [c]	Cleaner			1(1)	1(1)
	Microetch	1(3)			2(3)
OSP [d] (2 product lines)	Microetch	1(3)			2(3)
Immersion Silver	Cleaner			1(1)	1(1)
Immersion Tin [d] (2 product lines)	Immersion Tin			1(4)	

[a] Table entries are made in the following format - # of products meeting OSHA definition for the given hazardous property, as reported in the products' MSDSs (Total # of products in the process bath). A **blank** entry means that none of the products for the specific process bath meet the OSHA reporting criteria for the given property. Example: For the immersion tin bath, 1 (4) means that one of the four products in the bath were classified as explosive per OSHA criteria, as reported on the products' MSDSs.

[b] Data for pure chemicals (e.g., sulfuric acid) not sold as products were obtained from the Merck Index (Budavari, 1989) and included in category totals.

[c] Formulations for HASL process baths were unavailable because cleaner and microetch bath chemistries are not made specifically for the HASL process. Hazards reported for HASL bath types were reported as the worst case of the results of similar baths from other processes.

[d] For alternative processes with more than one product line, the hazard data reported represents the most hazardous bath of each type for the two product lines (e.g., of the microetch baths from the two product lines, the one with the most hazardous chemicals is reported).

Flammable - A flammable chemical is defined by OSHA [29 CFR 1910.1200(c)] as one of the following:

C   An aerosol that, when tested by the method described in 16 CFR 1500.45, yields a flame projection exceeding 18 inches at full valve opening, or a flashback at any degree of valve opening.

C   A gas that: 1) at ambient temperature and pressure, forms a flammable mixture with air at a concentration of 13 percent by volume or less; or 2) when it, at ambient temperature and pressure, forms a range of flammable mixtures with air wider than 12 percent by volume, regardless of the lower limit.

C   A liquid that has a flashpoint below 100 °F (37.8 °C), except any mixture having components with flashpoints of 100 °F (37.8 °C) or higher, the total of which make up 99 percent or more of the total volume of the mixture.

C   A solid, other than a blasting agent or explosive as defined in 29 CFR 1910.109(a), that is liable to cause fire through friction, absorption of moisture, spontaneous chemical change, or retained heat from manufacturing or processing, or which can be ignited readily and when ignited burns so vigorously and persistently as to create a serious hazard.

Two chemical products are reported as flammable according to MSDS data. Although the chemicals are flammable in their concentrated form, none of the chemical baths in the surface finishing line contain flammable aqueous solutions.

Combustible Liquid - As defined by OSHA [29 CFR 1910.1200(c)], a liquid that is considered combustible has a flashpoint at or above 100 °F (37.8 °C), but below 200 °F (93.3 °C), except any mixture having components with flashpoints of 200 °F (93.3 °C), or higher, the total volume of which make up 99 percent or more of the total volume of the mixture. None of the chemical products have been reported as combustible by their MSDSs.

Explosive - As defined by OSHA [29 CFR 1910.1200(c)], a chemical is considered explosive if it causes a sudden, almost instantaneous release of pressure, gas, and heat when subjected to sudden shock, pressure, or high temperature. Three chemical products are reported as explosive by their MSDSs.

Fire Hazard - A chemical product that is a potential fire hazard is required by OSHA to be reported on the product's MSDS. According to MSDS data, six chemical products are reported as potential fire hazards.

Corrosive, Oxidizer, and Reactive Surface Finishing Chemical Products

A breakdown of surface finishing chemical baths containing chemical products that are corrosive, oxidizers, or reactive in their concentrated form is presented in Table 3-39. The table also lists process baths that contain chemical products that may cause a sudden release of pressure when opened. The following lists OSHA definitions for chemicals in these categories and discusses the data presented in the table.

Corrosive - As defined by OSHA (29 CFR 1910.1200 [Appendix A]), a chemical is considered corrosive if it causes visible destruction of, or irreversible alterations in, living tissue by chemical action at the site of contact following an exposure period of four hours, as determined by the test method described by the U.S. Department of Transportation, 49 CFR Part 173, Appendix A. This term does not apply to chemical action on inanimate surfaces. A review of MSDS data found that 37 surface finishing chemical products are reported as corrosive in their concentrated form. Some surface finishing baths may also be corrosive, but MSDSs do not provide data for the process chemical baths once they are prepared.

Oxidizer - As defined by OSHA (29 CFR 1910.1200[c]), an oxidizer is a chemical other than a blasting agent or explosive as defined by OSHA [29 CFR 1910.109(a)], that initiates or promotes combustion in other materials, thereby causing fire either of itself or through the release of oxygen or other gases. Five chemical products are reported as oxidizers, according to MSDS data.

Table 3-39. Corrosive, Oxidizer, Reactive, Unstable, and Sudden Release of Pressure Possibilities for Surface Finishing Processes

Surface Finishing Process	Bath Type	Hazardous Property [a, b]				
		Corrosive	Oxidizer	Reactive	Unstable	Sudden Release of Pressure
HASL [c]	Cleaner Microetch	1(1) 3(4)	 1(3)		 1(3)	 1(4)
Nickel/Gold [d] (2 product lines)	Cleaner Microetch Catalyst Acid Dip	1(1) 3(4) 3(3) 1(1)	 1(4)			 1(4)
Nickel/Palladium/Gold	Cleaner Microetch Catalyst Activator Electroless Nickel Electroless Palladium	1(1) 3(4) 3(3) 1(4) 3(3) 1(3)	 1(4)			 1(4)
OSP [d] (2 product lines)	Cleaner Microetch	1(1) 3(4)	 1(3)			 1(4)
Immersion Silver	Cleaner Microetch	1(1) 1(3)	 1(3)		 1(3)	
Immersion Tin [d] (2 product lines)	Cleaner [c] Microetch Predip Immersion Tin	1(2) 2(2) 1(1) 3(4)				

[a] Table entries are made in the following format - # of products meeting OSHA definition for the given hazardous property, as reported in the products' MSDSs (Total # of products in the process bath). A **blank** entry means that none of the products for the specific process bath meet the OSHA reporting criteria for the given property. Example: For the immersion tin bath, 3(4) means that four of the five products in the bath were classified as corrosive per OSHA criteria, as reported by the products' MSDSs.

[b] Data for pure chemicals (e.g., sulfuric acid) not sold as products were obtained from the Merck Index (Budavari, 1989) and included in category totals.

[c] Formulations for HASL process baths were unavailable because cleaner and microetch bath chemistries are not made specifically for the HASL process. Hazards reported for HASL bath types were reported as the worst case of the results of similar baths from other processes.

[d] For alternative processes with more than one product line, the hazard data reported represents the most hazardous bath of each type for the two product lines (e.g., of the microetch baths from the two product lines, the one with the most hazardous chemicals is reported).

Reactive - A chemical is considered reactive if it is readily susceptible to change and the possible release of energy. EPA gives a more precise definition of reactivity for solid wastes. As defined by EPA (40 CFR 261.23), a solid waste is considered reactive if a representative sample of the waste exhibits any of the following properties: 1) is normally unstable and readily undergoes violent change without detonating; 2) reacts violently or forms potentially explosive mixtures with water; 3) when mixed with water, generates toxic gases, vapors, or fumes in a quantity sufficient to present a danger to human health or the environment (for a cyanide or sulfide bearing waste, this includes exposure to a pH between 2 and 12.5); 4) is capable of detonation or explosive reaction if subjected to a strong initiated source or if heated under confinement; or 5) is

explosive reaction if subjected to a strong initiated source or if heated under confinement; or 5) is readily capable of detonation or explosive decomposition or reaction at standard temperature and pressure. A review of MSDS data shows that none of the chemical products used in the surface finishing processes are considered reactive.

Unstable - As defined by OSHA (29 CFR 1910.1200[c]), a chemical is unstable if in the pure state, or as produced or transported, it will vigorously polymerize, decompose, condense, or will become self-reactive under conditions of shock, pressure, or temperature. Only two of the chemical products are reported as unstable, according to MSDS data.

Sudden Release of Pressure - OSHA requires the reporting of chemical products that, while stored in a container subjected to sudden shock or high temperature, causes a pressure increase within the container that is released upon opening. MSDS data indicates four chemical products that are potential sudden release of pressure hazards.

Surface Finishing Chemical Product Health Hazards

A breakdown of surface finishing process baths that contain chemical products that are sensitizers, acute or chronic health hazards, or irreversible eye damage hazards in their concentrated form is presented in Table 3-40. Also discussed in this section are surface finishing chemical products that are potential eye or dermal irritants and suspected carcinogens. The following presents OSHA definitions for chemicals in these categories and discusses the data in Table 3-40, where appropriate.

Sensitizer - A sensitizer is defined by OSHA [29 CFR 1910.1200 Appendix A (mandatory)] as a chemical that causes a substantial proportion of exposed people or animals to develop an allergic reaction in normal tissue after repeated exposure to the chemical. Sixteen chemical products are reported as sensitizers by MSDS data.

Acute and Chronic Health Hazards - As defined by OSHA (29 CFR 1910.1200 Appendix A), a chemical is considered a health hazard if there is statistically significant evidence based on at least one study conducted in accordance with established scientific principles that acute or chronic health effects may occur in exposed employees. Health hazards are classified using the criteria below:

C   acute health hazards are those whose effects occur rapidly as a result of short-term exposures, and are usually of short duration; and

C   chronic health hazards are those whose effects occur as a result of long-term exposure, and are of long duration.

Chemicals that are considered a health hazard include carcinogens, toxic or highly toxic agents, reproductive toxins, irritants, corrosives, sensitizers, hepatotoxins, nephrotoxins, neurotoxins, agents that act on the hematopoietic system, and agents which damage the lungs, skin, eyes, or mucous membranes.

Table 3-40. Sensitizer, Acute and Chronic Health Hazards, and Irreversible Eye Damage Possibilities for Surface Finishing Processes

Surface Finishing Process	Bath Type	Hazardous Property [a, b]				
		Sensitizer	Acute Health Hazard	Chronic Health Hazard	Carcinogen	Irreversible Eye Damage
HASL [c]	Cleaner	1(2)	1(1)	1(1)	1(1)	1(1)
	Microetch	2(3)	3(4)	3(3)		3(4)
Nickel/Gold [d] (2 product lines)	Cleaner		1(1)	1(1)	1(1)	1(1)
	Microetch	1(2)	3(4)	2(2)		3(4)
	Catalyst	1(2)	2(3)	1(2)		1(2)
	Acid Dip	1(1)	1(1)	1(1)		1(1)
	Electroless Nickel		2(2)	2(2)	1(2)	
	Immersion Gold		2(2)	2(2)		1(2)
Nickel/Palladium/Gold	Cleaner		1(1)	1(1)		
	Microetch	1(4)	3(4)	1(4)		3(4)
	Catalyst	1(3)	2(3)	1(3)		1(3)
	Activator		4(4)	2(4)	2(4)	1(4)
	Electroless Nickel	1(3)	3(3)	2(3)		2(3)
	Electroless Palladium		2(3)	1(3)	1(3)	3(3)
	Immersion Gold		1(2)	1(2)		
OSP [d] (2 product lines)	Cleaner		1(1)	1(1)		1(1)
	Microetch	2(3)	3(3)	3(3)		3(4)
Immersion Silver	Cleaner		1(1)	1(1)		1(1)
	Microetch	1(3)	2(3)	2(3)		2(3)
Immersion Tin [d] (2 product lines)	Cleaner	1(2)	1(2)	1(2)		1(2)
	Microetch	1(2)	1(2)	1(2)		2(2)
	Predip					1(1)
	Immersion Tin	2(4)	1(4)	1(4)	1(1)	2(4)

[a] Table entries are made in the following format - # of products meeting OSHA definition for the given hazardous property, as reported in the products' MSDSs (Total # of products in the process bath). A **blank** entry means that none of the products for the specific process bath meet the OSHA reporting criteria for the given property. Example: For the immersion tin bath, 2(4) means that three of the five products in the bath were classified as sensitizers per OSHA criteria, as reported by the products' MSDSs.

[b] Data for pure chemicals (e.g., sulfuric acid) not sold as products were obtained from the Merck Index (Budavari, 1989) and included in category totals.

[c] Formulations for HASL process baths were unavailable because cleaner and microetch bath chemistries are not made specifically for the HASL process. Hazards reported for HASL bath types were reported as the worst case of the results of similar baths from other processes.

[d] For alternative processes with more than one product line, the hazard data reported represents the most hazardous bath of each type for the two product lines (e.g., of the microetch baths from the two product lines, the one with the most hazardous chemicals is reported).

A review of MSDS data shows that 41 chemical products are reported as potentially posing acute health hazards, and 32 chemical products potentially pose chronic health hazards. OSHA does not require reporting of environmental hazards such as aquatic toxicity data, nor are toxicity data on MSDSs as comprehensive as the toxicity data collected for the CTSA. OSHA health hazard data are presented here for reference purposes only, and are not used in the risk characterization component of the CTSA.

Carcinogen - As defined by OSHA (29 CFR 1910.1200 Appendix A), a chemical is considered to be a carcinogen if: 1) it has been evaluated by the IARC, and found to be a carcinogen or potential carcinogen; 2) it is listed as a carcinogen or potential carcinogen in the Annual Report on Carcinogens published by the National Toxicology Program (NTP); or 3) it is regulated by OSHA as a carcinogen. A review of MSDS data indicates that seven chemical products are reported as potential carcinogens, by either NTP, IARC, or EPA WOE Classifications. Suspected carcinogens include nickel sulfate, thiourea, and various lead compounds that are commonly used in several processes. Suspected carcinogens are discussed in more detail in the human health and ecological hazards summary, Section 3.3.

Dermal or Eye Irritant - An irritant is defined by OSHA [29 CFR 1910.1200 Appendix A (mandatory)] as a chemical, that is not corrosive, but which causes a reversible inflammatory effect on living tissue by chemical action at the site of contact. A chemical is considered a dermal or eye irritant if it is so determined under the testing procedures detailed in 16 CFR 1500.41- 42 for four hours exposure. Table 3-40 does not include this term, because all of the surface finishing chemical products are reported as either dermal or eye irritants.

Irreversible Eye Damage - Chemical products that, upon coming in contact with eye tissue, can cause irreversible damage to the eye are required by OSHA to be identified as such on the product's MSDS. A review of MSDS data shows that 34 chemical products are reported as having the potential to cause irreversible eye damage.

Other Chemical Hazards

Surface finishing chemical products that have the potential to form hazardous decomposition products are presented below. In addition, chemical product incompatibilities with other chemicals or materials are described, and other chemical hazard categories are presented. The following lists OSHA definitions for chemicals in these categories and summarizes the MSDS data, where appropriate.

Hazardous Decomposition - A chemical product, under specific conditions, may decompose to form chemicals that are considered hazardous. The MSDS data for the chemical products in the surface finishing process indicate that over half of the products have the possibility of decomposing to form potentially hazardous chemicals. Each chemical product should be examined to determine its decomposition products so that potentially dangerous reactions and exposures can be avoided. The following are examples of hazardous decomposition of chemical products that are employed in the surface finishing alternatives:

C products used in the predip and immersion tin baths of the immersion tin process, or in the microetch and OSP baths of the OSP process, may decompose to release carbon monoxide and carbon dioxide gas;

C oxygen gas may be generated by some of the microetch baths from the nickel/gold process, posing a potential combustion hazard;

C thermal decomposition under fire conditions of certain chemical bath constituents in the nickel/gold or the nickel/palladium/gold process can result in releases of toxic oxide gases such as nitrogen, sulfur, or chlorine;

C some chemical products used in the nickel/gold and nickel/palladium/gold processes will release toxic chlorine fumes if they are allowed to react with persulfate compounds; and

C one product present in the cleaner bath of the immersion silver process will react with reactive metals to release flammable hydrogen gas.

Incompatibilities - Chemical products are often incompatible with other chemicals or materials with which they may come into contact. A review of MSDS data shows that over 80 percent of the surface finishing chemical products have incompatibilities that can pose a threat to worker safety if the proper care is not taken to prevent such occurrences. Reported incompatibilities range from specific chemicals or chemical products, such as acids or cyanides, to other environmental conditions, such as direct heat or sunlight. Chemical incompatibilities that are common to products from all the surface finishing processes include acids, bases, alkalies, oxidizing and reducing agents, metals, and combustible materials. Incompatibilities were also found to exist between chemical products used on the same process line. Individual chemical products for each process bath should be closely examined to determine specific incompatibilities, and care should be taken to avoid contact between incompatible chemicals and chemical products, textiles, and storage containers.

  The following are examples of chemical incompatibilities that exist for chemical products used in the surface finishing alternatives:

C some products in the catalyst baths of both the nickel/gold and nickel/palladium/gold processes are incompatible with strong bases, alkalies, and oxidizing agents;

C organic materials, combustible materials, and oxidizing and reducing agents should be kept away from the microetch bath of the OSP process, and strong alkaline materials should be avoided in the microetch baths for all of the processes; and

C persulfate should be avoided in the electroless palladium bath of the nickel/palladium/gold process, because it will react with the chemicals in the bath to release chlorine gas.

Other Chemical Hazard Categories - OSHA requires the reporting of several other hazard categories on the MSDSs for chemicals or chemical products that have not already been discussed above. These additional categories include chemical products that are:

C water-reactive (react with water to release a gas that presents a health hazard);

C pyrophoric (will ignite spontaneously in air at temperatures below 130 °F);

C stored as a compressed gas;

C   classified as an organic peroxide; or
C   chemicals that have the potential for hazardous polymerization.

A review of MSDS data indicates that none of the chemical products are reported as being water-reactive, pyrophoric, a compressed gas, an organic peroxide, or as having the potential for hazardous polymerization.

3.5.2   Hot Air Solder Leveling (HASL) Process Safety Concerns

Several unique process safety concerns arise from the operation of the HASL process, due to differences in the way the final surface finish is applied. Although the cleaning and microetch baths are similar to those used by the other alternatives, the solder finish is applied by the physical process of manually contacting the PWB with molten solder, rather than applying the surface finish through a chemical plating or coating process. The molten solder bath, which is typically operated at a temperature of up to 500 °F, poses several safety concerns, such as accidental contact with the molten metal by workers, exposure to acids in the flux, and the potential for fire.

Solder eruptions often occur during process startup as the solid solder is heated. Solder melts from bottom to top, and pressure may build up from thermal expansion causing the solder to erupt. Splattering of the melted solder onto workers could cause serious burns. Caution should be exercised during process startup to avoid worker injury. Heat resistant clothing, face shields, protective aprons, long sleeve gloves, and shoes should be required when working around the solder bath.

Fire is possible at the solder bath and the exhaust/ventilation system, although it does not occur frequently. When fire occurs, small amounts of hazardous gases, such as hydrogen chloride and carbon dioxide, can be released. Causes of fire include the build-up of carbon residual from the use of oil-based flux and other flammable materials kept too close to the process. Isolating flammable materials from the process area and regular cleaning of the HASL machine will prevent a fire from occurring.

Other safety concerns include workers exposed to small amounts of acid in the flux, lead in the solder bath, and to process chemicals in the cleaner and microetch baths. Risk from exposure to process chemicals is addressed in detail in Section 3.4, Risk Characterization. Like other surface finishing processes, federal safety standards and regulations concerning the HASL process can be found in CFR Title 29, Part 1910, and are available from the appropriate state office.

3.5.3   Process Safety Concerns

Exposure to chemicals is just one of the safety issues that PWB manufacturers may have to address during their daily activities. Preventing worker injuries should be a primary concern for employers and employees alike. Work-related injuries may result from faulty equipment, improper use of equipment, bypassing equipment safety features, failure to use personal protective equipment, and physical stresses that may appear gradually as a result of repetitive

motions (i.e., ergonomic stresses). Any or all of these types of injuries may occur if proper safeguards or practices are not in place and adhered to. An effective worker safety program includes:

C   an employee training program;
C   employee use of personal protective equipment;
C   proper chemical storage and handling; and
C   safe equipment operating procedures;

        The implementation of an effective worker safety program can have a substantial impact on business, not only in terms of direct worker safety, but also in reduced operating costs as a result of fewer days of absenteeism, reduced accidents and injuries, and lower insurance costs. Maintaining a safe and efficient workplace requires that both employers and employees recognize and understand the importance of worker safety and dedicate themselves to making it happen.

Employee Training

        A critical element of workplace safety is a well-educated workforce. To help achieve this goal, the OSHA Hazard Communication Standard requires that all employees at PWB manufacturing facilities (regardless of the size of the facility) be trained in the use of hazardous chemicals to which they are exposed. A training program should be instituted for workers, especially those operating the surface finishing process, who may come into contact with, or be exposed to, potentially hazardous chemicals. Training may be conducted by either facility staff or outside parties who are familiar with the PWB manufacturing process and the pertinent safety concerns. The training should be held for each new employee, as well as periodic retraining sessions when necessary (e.g., when a new surface finishing process is instituted), or on a regular schedule. The training program should inform the workers about the types of chemicals with which they work and the precautions to be used when handling or storing them, when and how personal protection equipment should be worn, and how to operate and maintain equipment properly.

Storing and Using Chemicals Properly

        Because the surface finishing process requires handling a variety of chemicals, it is important that workers know and follow the correct procedures for the use and storage of the chemicals. Much of the use, disposal, and storage information about surface finishing process chemicals may be obtained from the MSDSs provided by the manufacturer or supplier of each chemical or formulation. Safe chemical storage and handling involves keeping chemicals in their proper place, protected from adverse environmental conditions, as well as from other chemicals with which they may react. Examples of supplier recommended storage procedures found on the MSDSs for surface finishing chemicals are listed below.

C   store chemical containers in a cool, dry place away from direct sunlight and other sources of heat;
C   chemical products should only be stored in their properly sealed original containers and labeled with the common name of the chemical contents;

C   incompatible chemical products should never be stored together; and
C   store flammable liquids separately in a segregated area away from potential ignition sources or in a flammable liquid storage cabinet.

Some products have special storage requirements and precautions listed on their MSDSs (e.g., relieving the internal pressure of the container periodically). Each chemical product should be stored in a manner consistent with the recommendation on the MSDS. In addition, chemical storage facilities must be designed to meet any local, state, and federal requirements that may apply.

Not only must chemicals be stored correctly, but they must also be handled and transported in a manner that protects worker safety. Examples of chemical handling recommendations from suppliers include:

C   wear appropriate protective equipment when handling chemicals;
C   open containers should not be used to transport chemicals;
C   use only spark-proof tools when handling flammable chemicals; and
C   transfer chemicals using only approved manual or electrical pumps to prevent spills created from lifting and pouring.

Proper chemical handling procedures should be a part of the training program given to every worker. Workers should also be trained in chemical spill containment procedures and emergency medical treatment procedures in case of chemical exposure to a worker.

Use of Personal Protective Equipment

OSHA has developed several personal protective equipment standards that are applicable to the PWB manufacturing industry. These standards address general safety and certification requirements (29 CFR Part 1910.132), the use of eye and face protection (Part 1910.133), head protection (Part 1910.135), foot protection (Part 1910.136), and hand protection (Part 1910.138). The standards for eye, face, and hand protection are particularly important for the workers operating the surface finishing process where there is close contact with a variety of chemicals, of which nearly all irritate or otherwise harm the skin and eyes. In order to prevent or minimize exposure to such chemicals, workers should be trained in the proper use of personal safety equipment.

The recommended personal protective equipment for a worker handling chemicals is also indicated on the MSDS. For the majority of surface finishing chemicals, the appropriate protective equipment indicated by the MSDS includes:

C   goggles to prevent the splashing of chemical into the eyes;
C   chemical aprons or other impervious clothing to prevent splashing of chemicals on clothing;
C   gloves to prevent dermal exposure while operating the process; and
C   boots to protect against chemical spills.

Additional personal protective equipment recommended for workers operating the HASL process includes:

C   heat resistant gloves to prevent burns by accidental contact with molten solder; and
C   face shield to protect face and eyes from solder splatter.

Other items less frequently suggested include chemically resistant coveralls and hats. In addition to the personal protective equipment listed above, some MSDSs recommend that other safety equipment be readily available. This equipment includes first aid kits, oxygen supplies (SCBA), fire extinguishers, ventilation equipment, and respirators.

Other personal safety considerations are the responsibility of the worker. Workers should be prohibited from eating or keeping food near the surface finishing process. Because automated processes contain moving parts, workers should also be prohibited from wearing jewelry or loose clothing, such as ties, that may become caught in the machinery and cause injury to the worker or the machinery itself. In particular, the wearing of rings or necklaces may lead to injury. Workers with long hair that may also be caught in the machinery should be required to securely pull their hair back or wear a hair net.

Use of Equipment Safeguards

In addition to the use of proper personal protection equipment for all workers, OSHA has developed safety standards (29 CFR Part 1910.212) that apply to the equipment used in a PWB surface finishing process. Among the safeguards recommended by OSHA that may be used for conveyorized equipment are barrier guards, two-hand trip devices, and electrical safety devices. Safeguards for the normal operation of conveyor equipment are included in the standards for mechanical power-transmission apparatus (29 CFR Part 1910.219) and include belts, gears, chains, sprockets, and shafts. PWB manufacturers should be familiar with the safety requirements included in these standards and should contact their local OSHA office or state technical assistance program for assistance in determining how to comply with them.

In addition to normal equipment operation standards, OSHA also has a lockout/tagout standard (29 CFR Part 1910.147). This standard is designed to prevent the accidental start-up of electric machinery during cleaning or maintenance operations, and apply to the cleaning of conveyorized equipment as well as other operations. OSHA has granted an exemption for minor servicing of machinery, provided the equipment has other appropriate safeguards, such as a stop/safe/ready button that overrides all other controls and is under the exclusive control of the worker performing the servicing. Such minor servicing of conveyorized equipment can include clearing fluid heads, removing jammed panels, lubricating, removing rollers, minor cleaning, adjustment operations, and adding chemicals. Rigid finger guards should also extend across the rolls, above and below the area to be cleaned. Proper training of workers is required under the standard whether lockout/tagout is employed or not. For further information on the applicability of the OSHA lockout/tagout standard to surface finishing process operations, contact the local OSHA field office.

Occupational Noise Exposure

OSHA has also developed standards (29 CFR Part 1910.95) that apply to occupational noise exposure. These standards require protection against the effects of noise exposure when the sound levels exceed certain levels specified in the standard. No data were collected on actual noise levels from surface finishing process lines.

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